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Assessment of Waste Fuel Use in Cement Kilns

A. T. Kearney, Inc.
Alexandria, VA

Prepared for

Industrial Environmental Research Lab.
Cincinnati, OH

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ASSESSMENT OF WASTE FUEL USE IN CEMENT KILNS

by

Douglas L. Hazelwood
Francis J. Smith
A.T. Kearney, Inc.
Alexandria, Virginia 22313

Ellis M. Gartner
Portland Cement Association
Skokie, Illinois 60077

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Project Officers
Leo Weitzman and Harry Freeman
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
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This study was initiated to document current knowledge concerning the use of waste fuels in cement kilns. A number of plants have used wastes of relatively low toxicity to supplement their fuel needs. In addition, researchers in Canada, Sweden, and the United States have successfully demonstrated extremely high destruction efficiencies in cement kilns when burning highly toxic organic wastes. These studies indicate that a significant potential exists for the expanded use of cement kilns to safely dispose of many types of hazardous wastes generated in the United States.

The technical as well as economic factors affecting the use of cement kilns to destroy waste materials are reviewed. The recommendations derived from the study propose additional work required to thoroughly understand the impacts of this disposal technique.

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report examines the potential for utilizing commercial cement kilns for disposing of organic industrial wastes. The information presented will be of use in future efforts to develop and commercialize this technology. Researchers in the United States and abroad as well as cement plants contemplating the use of waste fuels will find this report helpful. Further information on the subject may be obtained by contacting the Incineration Research Branch, Industrial Pollution Control Division, IERL-Ci.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

This study was initiated to document current knowledge concerning the use of waste fuels in cement kilns. Technical as well as economic factors affecting the use of cement kilns to destroy waste materials are reviewed. The recommendations derived from the study propose additional work required to thoroughly understand the impacts of this disposal technique.

A number of plants have used wastes of relatively low toxicity to supplement their fuel needs. In addition, researchers in Canada, Sweden, and the United States have successfully demonstrated extremely high destruction efficiencies in cement kilns when burning highly toxic organic wastes. These studies indicate that a significant potential exists for the expanded use of cement kilns to safely dispose of many types of hazardous wastes generated in the United States and Puerto Rico.

The risks incurred in burning toxic wastes in cement kilns appear to be very low. Given proper controls, emissions of organic compounds are likely to be at or below analytical limits of detection. Particulate loadings will increase when burning halogenated wastes hence excess dust capture capacity may be required to effectively utilize this type of waste.

The economics of using waste fuels appears to be quite favorable for both cement plants and waste suppliers. Disposal of hazardous wastes through incineration or landfilling is likely to be more costly to waste generators than utilizing cement kilns. Cement plants using waste fuels could potentially reduce production costs by up to several dollars per ton.

This report was submitted in partial fulfillment of Contract No. 68-03-2586 by A. T. Kearney, Inc., under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period August 1979 to March 1981.

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SECTION 1

INTRODUCTION

The development of sound methods for disposing of hazardous industrial wastes is critical to ensuring the protection of public health and the environment. Although some restrictions and uncertainties exist as to the types and quantities of wastes that can be used as fuels in cement plants, cement kiln disposal is likely to be both environmentally and economically superior to conventional disposal methods such as landfilling and incineration.

A large volume of organic industrial wastes currently being generated in the United States and Puerto Rico could potentially be used as supplemental fuels in commercial cement kilns. Prior research has successfully demonstrated the safe destruction of several waste materials in cement kilns, including chlorinated hydrocarbons and highly toxic and stable wastes such as PCB's. Based on these studies, it appears that the wet-process cement plants located in the U.S. have the potential capacity to dispose of all chlorinated organic liquid wastes being generated in this country.

Fuel costs, which can represent up to 65 percent of the direct cost of producing cement clinker, could be substantially reduced through the use of waste fuels. Because of the positive value assigned to wastes used as fuels, the costs to waste generators disposing of wastes in cement kilns are expected to be relatively low. Regulations enacted under Subtitle C of the Resource Conservation and Recovery Act provide additional incentives for waste disposal in cement kilns. Under these regulations, wastes sent directly to a cement plant from the waste generator are exempt from most of the standards applicable to hazardous wastes.

The present study has focused on the status of waste fuel use in the cement industry. Section 2 of this report summarizes the major findings and conclusions of the study and Section 3 recommends actions to promote the expanded use of cement kilns to dispose of industrial wastes. The technical aspects of waste fuel use, including a review of previous research, are presented in Section 4. Environmental aspects of using waste fuels and appropriate controls are discussed in Section 5.

Section 6 analyses the economics of waste fuel use including equipment costs, fuel savings, and potential disposal revenues. An assessment of research needs is presented in Section 7.

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SECTION 2

CONCLUSIONS

The high cost incurred in disposing of hazardous wastes in an environmentally sound manner has led many industries to reduce waste generation rates through process changes and increased recycling. However, significant quantities of industrial wastes will continue to be generated which require disposal. At the present time, landfilling and incineration are the only disposal technologies employed on a significant scale in the United States. Cement manufacturing kilns could potentially be employed to dispose of large amounts of organic industrial wastes that would otherwise be incinerated or landfilled. Cement kiln disposal is not only more economical than other disposal techniques but, when properly controlled, appears to be environmentally superior to conventional disposal.

Because many waste products can be readily used as fuels or processed into supplemental fuels, a waste fuel market is rapidly developing in the U.S. Waste generators typically contract with a disposal firm to remove their unwanted byproducts and wastes. The disposal firm will, if possible, distill the organic wastes, reclaim any valuable components for use as feedstocks, sell that portion of the waste stream that can be used as a fuel, and dispose of residues through landfilling or incineration. Some materials, such as used lubricating oils, may simply be accumulated into large batches and sold directly as fuels. If the waste fuel does not contain significant quantities of toxic metals, halogenated materials, or toxic organics, it can usually be safely and economically substituted for coal, oil or natural gas in most industrial processes. However, the hazardous nature of combustion products from halogenated and highly toxic wastes precludes their use as fuels in most industrial processes, cement manufacture being the notable exception.

Cement kilns provide a suitable environment for the complete destruction and assimilation of even the most stable and toxic wastes. The high temperatures, long residence times and strong turbulence encountered in cement kilns have been shown to destroy waste materials such as PCB's to beyond analytical detection limits. In addition, the highly caustic environment of cement kilns acts as an effective scrubbing system for removing acidic residues, such as hydrochloric acid, that can be

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formed during the combustion of many wastes. The inability of other industries to use halogenated and highly toxic wastes as fuels combined with the demonstrated destructive capacity of cement kilns implies that a tremendous potential exists for using chlorinated wastes as supplemental kiln fuels.

According to EPA estimates, approximately 650,000 metric tons of chlorinated wastes are produced annually in the U.S., primarily in Texas and Louisiana. Wet-process cement kilns, the type most likely to use chlorinated wastes, are located throughout the U.S. including the Southern states. Based on past research, which indicates that chlorine may be introduced into wet-process cement kilns at rates of up to about 0.6 percent of the clinker production rate, U.S. cement plants have the capacity to dispose of all chlorinated wastes being generated in this country. In addition, large batches of wastes such as PCB-contaminated oils stored at sites around the country could be disposed of in cement kilns.

The economics of waste disposal in cement kilns has not been clearly demonstrated to date. However, because the additional capital expenditures and operating costs at a cement plant using waste fuels on a routine basis are anticipated to be relatively low, cement kiln disposal is expected to be economically attractive to both the cement industry and to waste generators. Older wet-process cement plants, which appear uniquely suited to using chlorinated waste fuels, are further attracted to this technology because it would help to regain some of the competitive edge now enjoyed by generally newer, more efficient, dry-process plants.

Despite the demonstrated safety of using cement kilns to dispose of waste products, some uncertainties still exist concerning the mechanisms of waste destruction within cement kilns. Until these mechanisms are better understood, the applicability of available performance data to different kiln systems and waste types will remain questionable.

The most significant barrier to the expanded use of waste fuels in cement kilns is the difficulty of obtaining the necessary public support for such programs. Public concern over potential health hazards has made state pollution control authorities reluctant to issue even limited-duration trial-burn permits for the use of any waste other than relatively innocuous materials. To overcome those fears and successfully foster the implementation of this technology on a significant scale, it will be necessary to expand the existing information base to the point where kiln performance can be reliably predicted through a detailed understanding of the mechanisms of waste destruction in cement kilns. These goals could be accomplished most effectively through a research/demonstration program conducted by the U.S. Environmental Protection Agency.

SECTION 3

RECOMMENDATIONS

The use of waste organic materials as supplemental fuels in cement kilns should be examined by the U.S. Environmental Protection Agency in order to determine if there is a need for regulations covering this activity. Currently, this activity is not covered by EPA regulations.

The necessary research can be accomplished most effectively through Federal sponsorship of research/demonstration projects at selected cement plants. These projects should be structured to gather the information required to fully understand the mechanisms controlling waste destruction in cement kilns and the variables affecting system performance. The projected research needs are discussed in detail in Section 7 of this report.

The pressing need to establish safe, environmentally acceptable disposal methods and sites will certainly be alleviated if this technique proves to be satisfactory.

SECTION 4

TECHNICAL ASPECTS OF WASTE FUEL USE

This Section describes the technology of cement production and the effects of added chemicals on cement properties. Past research in the use of waste fuels is also reviewed.

Although some work has been conducted using municipal refuse, discarded automobile tires and petroleum coke as supplemental fuels in cement kilns, this study was limited to the assessment of liquid organic industrial wastes as kiln fuels. Semi-solid wastes, such as industrial sludges, may be shown to be feasible kiln fuels in the future, however, firing problems and concerns over potential cement quality impacts have restricted research programs to the use of liquid wastes thus far.

CEMENT MANUFACTURING TECHNOLOGY

There are two basic cement manufacturing processes: the wet process and the dry process. Figures 1 and 2 illustrate the equipment commonly used in these processes. The wet process involves the grinding of raw materials with water to form a slurry containing 30 to 40 percent moisture. The slurry is blended, as required, and subsequently fed to the kiln. The dry process, on the other hand, does not introduce water during grinding and the raw materials are fed to the kiln in the form of a dry powder.

The wet process was the original cement manufacturing process, and until recently, had advantages over the dry process due to ease of handling and blending of raw materials as well as yielding higher quality clinker. However, improvements in dry blending and material handling techniques, in combination with lower energy consumption used in the dry process, has minimized the advantages of the wet process. Most new cement plants or production lines now use the dry process.

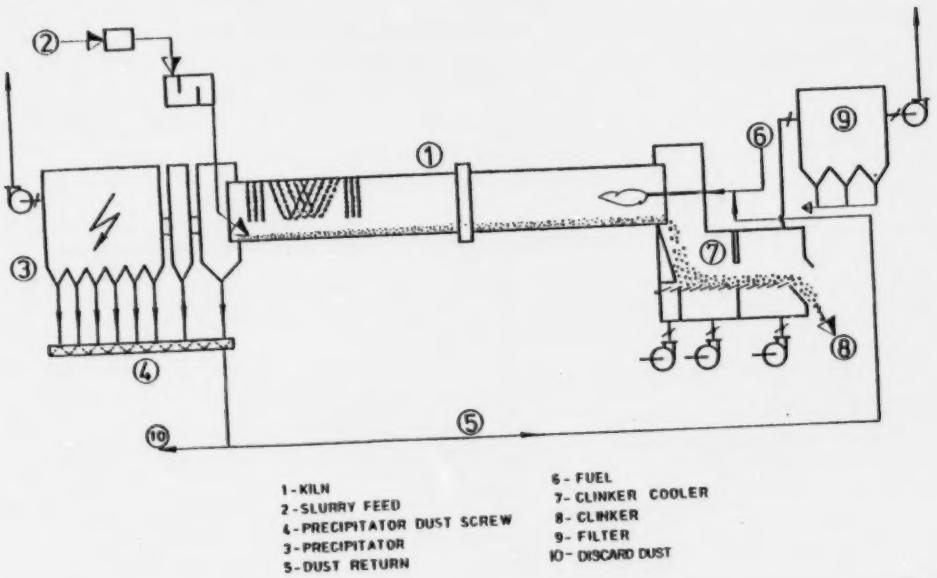

Figure 1. Typical Wet Process Kiln.

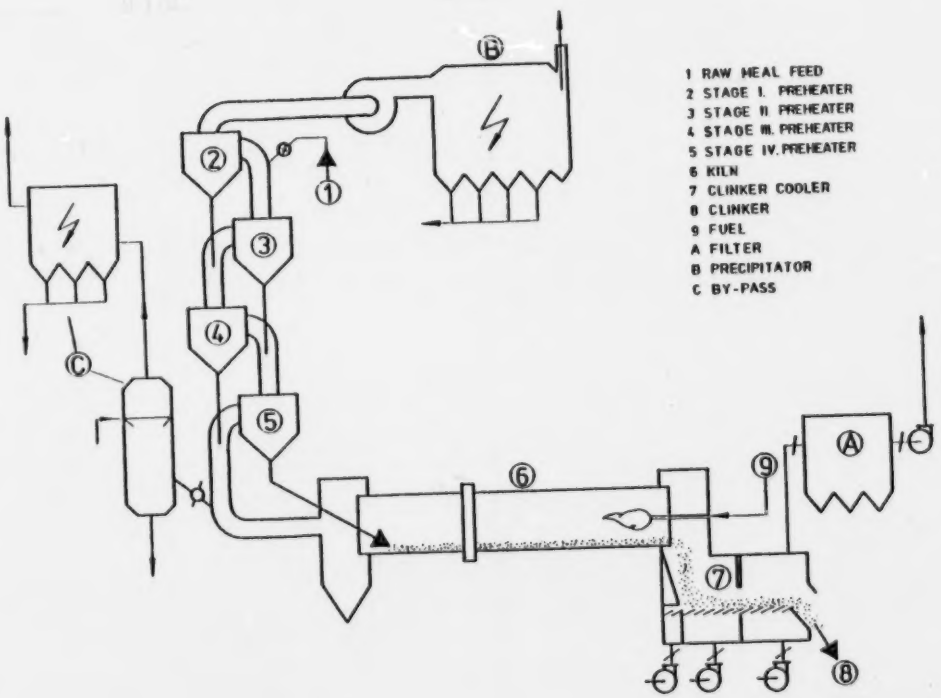

Figure 2. Typical Dry Process Kiln with Suspension Preheater

Roughly 95 percent of United States Cement production is portland cement.* There are five basic types of portland cement. Type I is "regular" portland cement which is used in general construction, and is produced in the largest quantities relative to the other types of cement. Type II is formulated for moderate heat-of-hardening and moderate sulfate-resisting applications. Type III is high-early-strength (HES) cement. Roads constructed of HES cement can be put in service faster than roads constructed from ordinary Type I cement. Type IV has a 15-35 percent lower heat of hydration than other types of cement. Finally, Type V portland cement is highly sulfate-resistant.

The rates of portland cement production since 1970 are presented in Table 1. Type I and II cements represent approximately 90-95 percent of total U.S. cement production shown. Only plants producing Type I and II cements have been employed to dispose of waste fuels to date. Because of the relatively small capacity for utilizing plants producing other cement types to dispose of wastes, this report addresses only the feasibility of using kilns producing Type I and II portland cements. However, there are few differences between all five types in terms of pyroprocessing conditions.

The standard unit of measure used by the cement industry is the short ton (equivalent to 2,000 pounds or 907 kilograms). For this reason, short tons and similar English units are used in presenting data in this report.

Portland cement clinker is produced by the controlled high temperature burning of calcareous material (e.g., limestone, oyster shells), argillaceous material (e.g., clay, shale), and siliceous materials (e.g., sand). These materials provide the basic elements required in cement: calcium, silicon, aluminum and iron. All elements are usually present in their fully oxidized form in cement clinker.

The blended and ground raw materials are fed into a kiln. The kiln is an inclined elongated steel cylinder lined with a refractory brick. Rotary kilns are used exclusively in both the wet and dry manufacturing processes in the U.S. Kiln length can be 60-760 feet with diameters of 6-25 feet.

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* Other types of cement include: pozzolan cement, high alumina cement, special or corrosion-resisting cements and mortars, regulated-set cement, and slag cements. (According to the Bureau of Mines, no slag cement has been produced in the United States since 1972.)

TABLE 1. U.S. PORTLAND CEMENT PRODUCTION

Year	Quantity (thousand short tons)
1970	73,407
1971	79,005
1972	81,432
1973	86,597
1974	79,482
1975	67,776
1976	71,922
1977	77,852
1978	83,849
1979	83,390
1980 (estimated)	76,500
1981 (estimated)	83,400

Source: Pit & Quary, January, 1981, page 65.

Raw materials are fed into the raised end of the kiln and travel down the incline to the other end where coal, oil, or gas is burned as a fuel. As was illustrated in Figure 1, chains are employed in most wet process kilns to aid in the transfer of heat from the hot combustion gases to the wet feed. The charge retention time in the kiln is roughly 1-4 hours while the gases will experience a retention time of approximately 10 seconds. Gas temperatures will typically reach a maximum of 3,000°F. Characteristic gas and charge temperature profiles are shown in Figure 3.

Quality control requires that the clinker be heated to a minimum temperature of 2600°F(1). It is impossible for a cement plant to allow temperatures to fall to the point where the efficiency of waste destruction is significantly compromised and still produce usable cement.

Reactions which occur during the conversion of the charge into clinker are: the evaporation of free water, evolution of combined water, evolution of carbon dioxide from carbonates (calcination), and the reaction between lime, silica, alumina, and iron to form the desired clinker compounds. The chemical make-up of cement and the effects of waste fuels on the cement product are discussed later in this section.

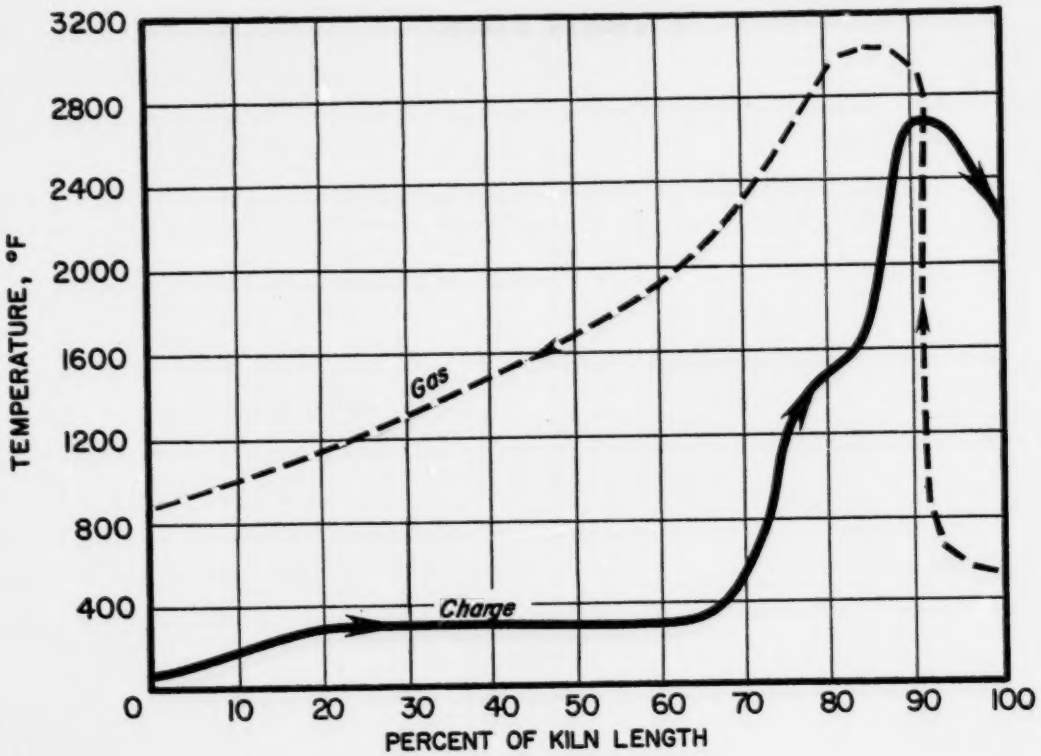

Figure 3. Typical Wet Kiln Temperature Profiles (1).

The product from the kiln consists of dark, hard nodules called clinker. These nodules are 3/4-inches or less in size and are cooled with air in a clinker cooler prior to storage and further processing. The hot recovered air from the cooler serves as secondary air in firing the kilns.

Part of the air from the clinker cooler, along with combustion gases and water vapor introduced in wet process systems, passes through the kiln, into some form of dust collection system, and finally out the stack. The remainder of the clinker cooler gases are passed directly to the dust collection system. The kiln and cooler exhausts carry entrained dust and volatilized matter from the kiln into the dust collection system. Varying concentrations of nitrogen oxides (NO_x) and sulfur oxides (SO_x) occur in the kiln exit gases.

Clinker is ground with about 3-6 percent gypsum (calcium sulfate), added to retard the cement's setting time, to form the final cement product. Other additives such as air-entraining, dispersing, and "water-proofing" agents can be added.

One of the most significant new technological developments in the cement industry in recent years is the suspension preheater. This unit can only be used in dry processes, where it is installed just upstream of the kiln. The preheater consists of a series of cyclones connected by pipes through which gases from the kiln pass upward counter-current to the dry raw material flowing down and around the cyclones.

Suspension preheaters offer a number of advantages. First, they provide conservation of energy through the transfer of heat from the gas into the raw material feed dust. This, in turn, leads to roughly 40 percent calcination of the feed before it enters the kiln.

The addition of a separate combustion chamber or "precalciner" to the preheater system can further increase the amount of calcination achieved. Up to 90 percent of the required calcination can be obtained with such systems before the feed enters the kiln. These systems are becoming increasingly popular as they permit greater throughput for any given kiln size.

In designing new plants, the use of preheaters with or without precalciners means that the rotary kiln need only be about half the length as would be required without a preheater. Preheaters have, however, been found to present material flow problems when chlorinated waste fuels are burned.

PREVIOUS STUDIES

Several cement plants in the United States and abroad have experimented in the past with industrial wastes as fuel sources, however, most of this work has not been documented. Contacts with cement manufacturers indicate that many companies have conducted limited duration trials with waste fuels. The majority of these trials have involved waste oils and spent non-halogenated solvents.

The waste fuel experiments which have been documented are reviewed below. Section 5 contains detailed discussions of emissions testing results from these studies.

St. Lawrence Cement - Canada

Between March 1974 and January 1976, the St. Lawrence Cement Company Limited located in Mississauga, Ontario, conducted two separate experiments in which wastes were utilized to supplement fuel oil use in commercial cement kilns. The first of these experiments involved metal-contaminated waste oils and the second chlorinated organic liquids.

Waste Oil Experiment--

Approximately 330,000 gallons of used lubricating oil were burned at St. Lawrence Cement between March and May, 1974 (2). The kiln utilized for this work was a dry system with dual four-stage preheaters equipped with a by-pass system. During the experiment, the kiln produced up to approximately 3,500 tons per day of clinker.

The kiln utilized in this experiment was oil-fired. Waste oil was pumped and injected separately from the number six oil normally used in the kiln. The heating value of the waste oil used varied between about 13,600 and 19,300 BTU/lb or 106,000 to 143,000 BTU/gal. Waste fuel was used for about one third of the total kiln fuel requirement.

The principal focus of this study was on the contaminants lead, zinc, phosphorus, and bromine present in the waste fuels. Approximate concentrations of these materials in the waste oils were:

Lead	0.6%
Bromine	0.15%
Zinc	0.1%
Phosphorus	0.1%

Stack testing revealed no increased kiln emissions of these elements that could be attributed to the waste oils. Particulate emissions from the kiln were actually found to decrease during periods of waste fuel use.

The lead, zinc, and phosphorus present in the waste oil were largely retained in the clinker product. Most of the bromine was retained as bromide in the kiln dust. The quality of the cement was in no way impacted by the use of waste fuels.

Experiments With Chlorinated Wastes and PCB's--

In June, 1975, St. Lawrence Cement began experiments using a mixture of chlorinated aliphatic materials in their dry suspension-preheater kiln (3). It was found that the chlorine present in the waste fuels preferentially formed easily volatilized alkali chlorides. At normal kiln temperatures these materials are volatilized and carried from the kiln with the gas stream. Material build-up problems were encountered in the kiln system when these alkali chlorides condensed on the raw meal in the preheater and were returned to the kiln. This problem can be overcome by removing a portion of the kiln exhaust gas as it enters the preheater system. As the quantity of chlorine introduced into the kiln increases, the amount of exhaust gases that must be removed at the bypass also increases.

The St. Lawrence experiments using a dry kiln were aborted after a few days of operation. This was due in part to a

continual plugging problem experienced at the bypass duct resulting from its inadequate size. It was also found that particulate stack emissions increased dramatically because of the inability of the dust collection equipment to handle the higher gas flow rates required to properly cool the bypass gas stream. It was decided, therefore, to continue the experiments using one of the wet-process kilns of the St. Lawrence Cement Company.

Between October, 1975 and January, 1976 three experiments were conducted using an oil-fired, 1,000 ton per day, wet process kiln. Each experiment involved a different chlorinated waste fuel. The three wastes used during the tests are described in Table 2 on the following page.

The waste fuels used in this experiment had typical heating values of 9,300 to 11,900 BTU/lb or 94,600 to 117,800 BTU/gal and were used to supplement number six fuel oil use. The fuel replacement level achieved with the wastes averaged about 12 percent.

Fuel requirements for the kiln were reduced by approximately 65 percent of the actual energy content of the wastes burned. The remaining 35 percent of the wastes' energy content was expended in volatilizing the alkali chlorides formed by the addition of chlorine-bearing fuels. (This utilization value is for a waste containing 40 percent chlorine by weight and would change as the waste composition changed.)

The key factor limiting the amount of wastes that could be introduced into the kiln was the wastes' chlorine content. When chlorine was fed to the kiln at too high a rate, alkali chloride rings were formed in the kiln which disrupted operations.

The maximum rate of chlorine addition during the tests was 0.79 percent relative to clinker weight. (This figure includes chlorine present in the raw feed and the No. 6 fuel oil.) At rates below 0.7 percent, no process disruptions occurred, however, variations in kiln chemistry between plants make the transferability of tolerance levels questionable. From these tests it is estimated that chlorine can probably be added to a typical wet process kiln at rates up to 0.4-0.7 percent without disrupting operations.

During all tests at St. Lawrence cement, none of the stable high-molecular-weight compounds present in the fuels, including PCB's, were detected in the kiln emissions. Extremely low levels of light-weight organochloride compounds (such as dichloromethane) were detected in emission samples. The amounts of these compounds detected in relation to background levels, coupled with the absence of any detectable amounts of the highly stable wastes burned, indicates that the low molecular weight compounds found are not materials that have escaped destruction.

TABLE 2. CONTENT OF WASTE FUELS USED IN CANADIAN TEST

Waste Type	Amount Used (Gallons)	Contents (Percent)
Chlorinated aliphatics[a]	24,900	18.8 chloropropane & propene, ethyl chloride, and dichloromethane
		16.5 dichloroethane
		15.6 chlorobenzene
		10.5 1,1,2-trichloroethane
		11.3 multichlorinated butanes, butenes, hexanes, and hexenes
		27.3 other chlorinated aliphatics
Chlorinated aromatics[b]	19,400	52.2 chlorotoluene
		18.9 hexachlorocyclopentadiene and associated complexes
		8.5 octachlorocyclopentene
		20.4 other chlorinated aromatics
Chlorinated aromatics plus PCBs[b]	11,700	28.5 chlorotoluene
		23.3 tetrachlorobiphenyls
		16.0 trichlorobiphenyls
		9.1 pentachlorobiphenyls
		5.5 dichlorobiphenyls
		17.6 other chlorinated aromatics

Notes: (a) Aliphatics are a class of carbons compounds with the carbon atoms in open chains

(b) Aromatics are compounds containing one or more benzene rings.

Source: Mac Donald, L.P., et.al., "Burning Waste Chlorinated Hydrocarbons in a Cement Kiln," Fisheries and Environmental Canada, March, 1977.

It appears likely that these compounds originate in the feed water used to blend the clinker constituents. Also it may be possible that a mechanism exists by which light-weight organochlorides are formed in the cooler end of the kiln.

Particulate emissions were found to increase when chlorine-bearing wastes were burned in the kiln. This is not surprising since the chlorine from the wastes will combine with potassium and sodium in the kiln to form volatile alkali chlorides which are carried from the kiln with the exhaust gases. While the increased dust loading experienced by the dust collection equipment can result in increased particulate emissions, it is quite feasible that collection equipment can be modified to adequately control emissions if chlorine-bearing fuel supplements are to be used on a routine basis.

Particulate emissions from the stack, usually about 0.5 pounds per ton of clinker produced, increased during the tests by an average factor of 2.2. During the trial with aliphatic wastes, particulate emissions averaged six times their normal level. This coincided with extensive ring formation which required a kiln shut-down. In spite of the high emissions, maximum ground level concentrations of particulates were calculated to be at least a factor of ten lower then the Ontario standard of 100 micrograms per cubic meter. (Because of variations in kiln chemistry and dust collection system efficiency, particulate emission data is not directly transferable between plants.)

The only change in cement quality which resulted from the use of chlorinated wastes was a slight reduction in clinker alkali content. This reduction was in direct stoichiometric proportion to the amount of chlorine added and is a desirable change. (A reduced alkali content is frequently considered beneficial to cement quality.) Thus, it appears that chlorine added with fuel will have an effect identical to that of chlorine added with the feed.

Peerless Cement - Detroit, Michigan

In December, 1976, Amcord, Inc. conducted a test burn of PCB wastes at its Peerless Cement plant in Detroit, Michigan (4). The Peerless facility is a coal-burning wet process plant having a production capacity of 2,160 tons per day. The waste utilized in this experiment contained approximately 40 percent PCB Arochlor 1260 from utility transformers. The waste was injected into the coal flame at rates up to 0.75 gallons per minute using an auxiliary burner.

Testing during the experiment consisted solely of monitoring for PCB emissions in the stack gases. No stack emissions of PCB's were identified which could be attributed to the use of PCB-bearing oils in the kiln.

Both during the waste-fuel burning and during background tests when no PCB's were burned, PCB's were found in the stack at rates from 5.9 to 44.9 milligrams per minute. The highest concentrations of PCB's in the stack occurred when no PCB's were being burned. Because PCB's were detected in the plant's feed water, it was determined that the materials detected in the stack entered the kiln in the make-up water used to blend the raw feed slurry. This conclusion is supported by chromatograph "finger prints" of PCB's detected in the stack which did not match those of the waste fuels.

Stora Vika Cement Factory - Sweden

Experiments were conducted using chlorinated wastes as fuels in a cement kiln at Stora Vika, Sweden, about 70 kilometers south of Stockholm, between February and July, 1978 (5,6). The kiln utilized in this work was a coal-fired wet-process kiln producing approximately 620 tons per day of clinker.

The test program involved experiments with four different types of chlorinated wastes. The wastes used are described in Table 3. The average chlorine concentration in these wastes was 17 percent. Chlorine addition averaged 0.35 percent relative to clinker weight and reached a maximum of 0.8-0.9 percent. Up to a chlorine input rate of 0.6-0.7 percent, no problems were encountered with kiln operations. At higher rates, however, alkali chloride rings began forming in the kiln. These rings disappeared when chlorine introduction was decreased.

With the exception of one experiment involving Freon, none of the constituents of the wastes used in the kiln were detected in the stack gases. The quantity of Freon detected was small and corresponds to a minimum destruction efficiency of 99.99986 percent.

Small amounts of chloroform, up to 52 parts per billion were detected in the stack emissions during some of the experiments. Analyses were also conducted for dioxins and furans which can be formed during the combustion of chlorophenols and phenoxy acids (5.6). In one experiment, extremely low concentrations of what may have been heptachlorodibenzo-p-dioxin, octachlorodibenzo-p-dioxin, or octachlorodibenzofuran were identified. However, the amount detected was too small to permit confirmation of the identity of the compound detected.

TABLE 3. WASTE FUELS USED IN SWEDISH EXPERIMENTS

Waste Type	Amount Used	Contents
Chlorinated Aliphatics	13,000 gallons	70 percent isopropanol
		28 percent dichloromethane
		2 percent trichloroethylene
PCB in oil	4,200 gallons	Arochlor 1242 in oil
		15.7 percent total chlorine content
Chlorophenols and Phenoxyacids	2,600 gallons	94 percent xylene
		2 percent MCPP (a)
		2 percent MCPA (b)
		2 percent chlorophenols and phenoxy acids
Trichlorotrifluoroethane	560 pounds	Freon TF

Notes: (a) MCPP = 2-(2-methyl-4-chlorophenoxy)-propionic acid.

(b) MCPA = 2-methyl-4-chlorophenoxyacetic acid

Source: Ahling, B., "Combustion Test with Chlorinated Hydrocarbons in a Cement Kiln at Stora Vika Test Center," Swedish Water and Air Pollution Research Institute, Stockholm, March 16, 1978.

No dioxins or furans containing four or six chlorines, the more toxic types of dioxins and furans, were detected during the experiments.

Dust emissions from the plant, which averaged 32 milligrams per cubic meter (at STP) during baseline tests, increased during the experiments to an average value of 101 milligrams per

cubic meter. As in the Canadian experiments, this was due primarily to an increase in potassium chloride concentrations in the flue gases leaving the kiln.

Both the Swedish and Canadian facilities employ electrostatic precipitators for controlling dust emissions. It appears that alkali chlorides generated when chlorine is added to the kiln have a higher resistivity than typical kiln dust. This may require "tuning" of the precipitator stages in order to capture the dust most effectively.

In the course of the experiments, the clinker product showed no decrease in strength. A slight reduction in clinker alkali content was realized. However, unlike the Canadian experiments, the change was not as much as predicted by stoichiometric calculations. This discrepancy may be due to errors in constructing a mass balance that resulted from a large variance in material flow rates during the tests.

EFFECTS OF MINOR AND TRACE ELEMENTS ON CEMENT MANUFACTURE AND USE

Significant potential exists for disposing of many wastes in cement kilns in a safe and efficient manner. However, the indiscriminant use of waste fuels in cement kilns can result in unacceptable emission levels, process failures, and decreased cement quality. With a complete knowledge of the constituents of the waste being utilized and an understanding of kiln chemistry, it is possible to supplement or possibly even replace fossil fuel use with little or no negative impacts. This subsection summarizes the likely effects of typical waste fuel constituents on the cement manufacturing process and cement quality.

In general, the tolerance of a particular process for chemicals that may be present in waste fuels will depend on the existing kiln chemistry. The kiln chemistry itself is dependent on the constituents present in the raw feedstocks and the fuel and is likely to vary between geographic regions. These basic differences between cement plants prevent the formulation of set tolerance levels for chemicals that may be introduced into the cement through waste fuels.

The following paragraphs summarize the variables controlling the acceptable levels for various elements in cement and present probable tolerance levels based on available information. Because organic materials are believed to be completely dissociated into their constituent elements soon after being injected into a kiln system, the effects of organic compounds can be best assessed by examining the effects of their constituent elements.

The following discussions of individual elements are arranged by periodic table groupings. All percentages are weight/weight percentages unless otherwise stated.

Group I Elements

Group I elements consist of hydrogen, lithium, sodium, potassium, rubidium, and cesium.

Hydrogen (H)--
Hydrogen, introduced in the form of water, is very common in all kilns and apparently has little effect on clinker properties.

Lithium (Li)--
Lithium generally occurs in cement in concentrations of 0.02 percent or less. It may be beneficial in retarding alkali-aggregate reactions and improving burnability at levels up to one percent (7,8,9).

Sodium (Na)--
Sodium is present in most cement clinkers. It may also occur in the cement kiln dust as NaCl, Na_2SO_4 or Na_2CO_3. In practice, it is believed that sodium preferentially dissolves in the aluminate phase, $(CaO)_3Al_2O_3$, where it displaces CaO giving a so-called "alkali-aluminate" of approximate composition $Na_2O(CaO)_8(Al_2O_3)_3$. This tends to increase the free lime and the aluminate content of the clinker and may also reduce burnability appreciably. If excess sulfur is present, the sodium will instead form Na_2SO_4 which usually occurs in the clinker as a crystalline solid solution of approximate composition $K_3Na(SO_4)_2$, known as aphthitalite or glaserite. Since alkali-aluminates in clinker can detrimentally affect the cement's setting and hardening properties, it is preferable to balance the sodium with sulfur so that most of the clinker sodium is in the form of sulfates.

Excessive concentrations of sodium can result in "high alkali" cements which may have an expansive reaction with certain types of aggregates resulting in concrete cracking. The American Society for Testing Materials (ASTM) sets a total alkali specification for "low alkali" cements(10) determined as follows:

$$\text{Total alkalies} = Na_2O + 0.658\ K_2O \qquad (1)$$

Total alkalies, as calculated in (1), are expressed as percent Na_2O and cannot exceed 0.6 percent for "low alkali" cements. Excessive alkalies may also result in material buildup in kilns (11,12,13).

Potassium (K)--

Potassium is present in most cement clinkers. It may also be present in kiln dust as KCl, K_2SO_4 or K_2CO_3. Potassium preferentially forms K_2SO_4 in the presence of sulfur and oxygen. The sulfate usually occurs in the clinker as a crystalline solid solution called aphthitalite or glaserite of approximate composition $K_3Na\ (SO_4)_2$. Arcanite, K_2SO_4, is also formed in clinkers. Excess potassium in clinker tends to enter the belite phase, $(CaO)_2\ SO_3$, forming the so-called "alkali-belite" of approximate composition $K_2O\ (CaO)_{23}\ (SO_3)_{12}$. Since the presence of alkali-belites can detrimentally affect cement quality, it is preferable to balance the potassium with sufficient sulfur such that most of the clinker potassium is in the form of sulfates. Excessive concentrations of potassium in the cement can cause alkali-aggregate reactions similar to those discussed under sodium.

The ASTM sets a total alkali specification for "low alkali" cements as presented in equation (1). Excessive alkalis may also result in material buildup within the kiln system and the formation of rings in the kiln (11,12,13).

Rubidium (Rb) and Cesium (Cs)--

Rubidium and cesium generally occur in cements in concentrations of 0.02 percent or less. They may be expected to behave very similarly to potassium, forming stable sulfates and volatile chlorides (7).

Group II Elements

The Group II elements consist of beryllium, magnesium, calcium, strontium, and barium.

Beryllium (Be)--

Beryllium has not been measured in cement clinker in significant quantities. Its behavior in a cement kiln cannot be predicted although due to the stability and involatility of its oxides it appears probable that it primarily would be retained in the clinker.

Magnesium (Mg)--

Magnesium is present in virtually all cement clinkers. It commonly occurs in limestone and other raw materials and is frequently considered beneficial in small quantities as it improves burnability. The ASTM specifies a maximum MgO content of six percent to avoid destructive concrete expansion (10).

Calcium (Ca)--

Calcium is a major component of all cement. Typically, portland cement clinkers contain 61-66 percent CaO.

Strontium (Sr)--

Strontium frequently occurs in cement in the range of 0.05-0.4 percent. It appears to be marginally harmful to cement strength and other physical characteristics. Excessive SrO could increase free lime content if not counteracted. This may in turn cause deleterious expansions in concrete in concentrations greater than 1-2 percent (7,14,15).

Barium (Ba)--

Barium is usually found in cement clinker at levels below 0.2 percent. It is reported to produce small increases in cement paste shrinkage but may also increase strengths. Excessive BaO will increase free lime content if not counteracted. Free lime concentrations above 1-2 percent may cause deleterious expansion of some concretes (7,9,16).

Group III Elements

The Group III elements consist of boron, aluminum, gallium, indium, and thallium.

Boron (B)--

Boron is usually present in cement in trace quantities. Boron appears to be sensitive to the presence of other minor elements as it exhibits erratic behavior when added to cement. Concentrations of boron oxide as low as 0.04 percent have been reported to have deleterious effects on cementing properties. However, beneficial effects have been observed in some instances (16,17).

Aluminum (Al)--

Aluminum is a component of all cements and is usually present (in solution with other compounds) in concentrations of 2-7 percent as Al_2O_3. The ASTM limits Al_2O_3 concentrations to six percent and tricalcium aluminate ($3CaO.Al_2O_3$) concentrations to eight percent in type II portland cement (10).

Gallium (Ga)--

Gallium presumably occurs only in trace quantities in cement raw materials. Gallium apparently is commonly found in coal in concentrations of 4-10 ppm. No information is available on gallium in cement kiln systems (18,19,20).

Indium (In)--

Indium presumably occurs only in trace quantities in cement raw materials. Levels of indium in coal are probably on the order of 0.07 ppm. Indium is relatively volatile and, in a kiln system, is likely to be deposited in the kiln dust. No information is available on indium in cement kiln systems (20, 21).

Thallium (Tl)--

Thallium usually occurs only in trace quantities in cement raw materials. Thallium concentrations in coal are probably in the order of 1 ppm but may be higher. Thallium is rather volatile and is likely to concentrate in the kiln dust (21).

Group IV Elements

The Group IV elements are carbon, silicon, germanium, tin, and lead.

Carbon (C)--

Carbon is present in all kiln systems, mainly as CO_2. It is not found to any great extent in clinkers and does not usually affect cement quality when introduced to the kiln.

Silicon (Si)--

Silicon is present in all portland cement as the oxide, SiO_2 in various compounds. Typical SiO_2 concentrations are 19-25 percent with a minimum of 21 percent required for type II portland cement. Alite or tricalcium silicate ($3CaO.SiO_2$) as well as belite or dicalcium silicate ($2CaO.SiO_2$) concentrations are restricted in some special portland cements (10).

Germanium (Ge)--

Germanium is a normal trace element in cement raw materials and in coal. It is probably present in clinkers as the involatile oxide GeO_2. It appears unlikely that small amounts of germanium would seriously affect cement production or properties.

Tin (Sn)--

Tin is a normal trace element in cement raw materials and in coal. The effects of appreciable tin concentrations in cement are not understood. Tin is reasonably involatile and is likely to be retained in the cement clinker (21).

Lead (Pb)--

Experiments with lead-contaminated waste oils at St. Lawrence Cement in Canada indicate that most lead introduced with the fuel is retained in the clinker. Stack emissions were found to average about 0.04 percent of the lead introduced in the fuel. Experiments were conducted using up to 0.019 percent lead (relative to clinker). Cement quality was not affected for clinker lead concentrations of 0.001-0.007 percent. Effects of higher concentrations are not yet certain. Lead salts, when added as admixtures to clinker in concentrations of 0.2 percent, can seriously retard setting (2,22,23,24).

Group V Elements

The group V elements are nitrogen, phosphorus, arsenic, antimony, and bismuth.

Nitrogen (N)--

Nitrogen is present as the major component of the kiln gas stream. Nitrogen contained in fuels is believed to contribute to kiln NO_x emissions. Levels of nitrogen in coal and other fuels are variable but frequently are as high as 1-2 percent. Raw feed materials can typically contain up to 0.1 percent nitrogen while cement clinkers, depending on whether they are produced under oxidizing or reducing conditions, will contain a few parts per million nitrogen up to 0.05 percent nitrogen, respectively.

Phosphorus (P)--

Phosphorus sometimes occurs at levels of one percent or more in raw materials. It is almost completely retained by the clinker. Levels of the oxide, P_2O_5, of 0.5 percent or less in cement will probably not affect cement properties. High levels of P_2O_5, above 2.5 percent, are known to seriously retard strengths. Intermediate levels of phosphorus are tolerable when balanced by the addition of fluorides and possibly chlorides (16,25).

Arsenic (As)--

Arsenic tends to form the oxides As_2O_3 and As_2O_5. The pentoxide decomposes to the trioxide at a fairly low temperature which in turn volatilizes at about 400°F (193°C). Therefore, arsenic is likely to be deposited with the kiln dust. It is believed that As_2O_5 decreases the rate of alite (tricalcium silicate) formation in clinkering reactions (18,20,26).

Antimony (Sb)--

There is little knowledge of the effects of antimony on cement production. Antimony probably forms the acidic oxides Sb_2O_3 and Sb_2O_5. Antimony present in the kiln is believed to be deposited in the kiln dust (18,20,27).

Bismuth (Bi)--

The effects of bismuth on cement production are not understood. Bismuth tends to form the oxides Bi_2O_3 and Bi_2O_5, the pentoxide being the prevelant form at higher temperatures. Bismuth may be deposited in the kiln dust.

Group VI Elements

The group VI elements are oxygen, sulfur, selenium, and tellurium.

Oxygen (O)--

Oxygen is present in all kiln systems. Most compounds present in the kiln are oxides.

Sulfur (S)--

Sulfur is present in virtually all kiln systems. It frequently originates from the kiln fuel although it may also be found in some feed materials. Some sulfur escapes the kiln as SO_2. However, it preferentially forms the alkali sulfates, K_2SO_4 and Na_2SO_4, which usually occur in clinker as the crystaline solid $K_3Na(SO_4)_2$, known as aphthitalite or glaserite. Sulfur in excess of that required to balance the alkalies will usually form calcium salts. Excess sulfur can lead to deleterious expansion of the cement paste. ASTM specifies a maximum SO_3 concentration of 2.3-5.0 percent depending on the type of portland cement being manufactured and the amount of tricalcium aluminates present (10,28).

Sulfur is typically ground into the finished clinker in the form of gypsum to improve setting and hardening characteristics. It appears, however, that the sulfur present in the unground clinker may not add to the quality of the cement as does the sulfur present in the added gypsum. The sulfur in the unground clinker, in effect, may count against the limit of SO_3 allowed while not actually enhancing the cement quality as does the gypsum. However, this is not always the case.

Sulfur is considered rather volatile in a kiln. A significant amount of sulfur will usually exit the kiln with the gas stream as SO_2. Excess sulfur can result in material buildups in some kiln systems.

Selenium (Se) and Tellurium (Te)--

Selenium and tellurium are trace elements in cement manufacture, probably originating in coal fuels. It is probable that selenium and tellurium introduced into a kiln will be concentrated in the gas stream and exit with the kiln dust (18,20).

Group VII Elements

The group VII elements are fluorine, chlorine, bromine, and iodine.

Fluorine (F)--

Fluorine is commonly present in the raw materials used to produce cement. Fluorine can be retained in the clinker in the form of fluorosilicates, potassium fluoride, or sodium fluoride. They can also be carried out of the kiln with the kiln dust. It appears that in concentrations of 0.5 percent or less, fluoride seldom causes harmful side effects and actually improves the burnability of clinker. Higher levels of fluoride can lead to both operational and quality problems depending on the compounds formed in the kiln (16,31).

Chlorine (Cl)--

Chlorine is commonly found in the raw materials used to produce cement. It preferentially reacts with the alkali metals giving KCl and NaCl, both of which are volatile at clinkering temperatures. As a result, very little chlorine is found in most cement clinkers. The alkali chlorides are usually carried from the kiln in the gas stream. For this reason, additional chlorine is sometimes introduced with the feed in order to reduce clinker alkali content.

Introduction of additional chlorine into kilns equipped with preheaters or into kilns utilizing dust recycle can lead to material build-up within the system and the formation of hard rings on the kiln interior. Experiments conducted in Canada found that chloride levels in the raw feed and fuel totaling more than 0.015 percent (relative to feed) are likely to produce build-up in kilns using preheaters. These problems may be overcome by partially bypassing the preheater or discarding a portion of the captured dust. However, if large amounts of chlorine are introduced into the kiln, even these measures may not be sufficient to prevent problems (3,32).

Additional chlorine introduced in the kiln will increase the amount of dust exiting the kiln. This may result in increased plant emissions if the air pollution control devices installed at the plant are unable to handle the increased dust loads. High chloride levels may also result in increased deterioration rates of the refractory bricks in some kilns. Chlorine normally will not be present in the clinker product in any appreciable concentrations and, as such, will not significantly affect cement quality. If under unusual circumstances, excessive chlorine occurs in the cement, serious setting or corrosion problems may result.

Experiments in Canada and Sweden using chlorine-bearing fuels in wet-process kilns have been successful at chlorine feed levels up to approximately 0.7 percent relative to clinker weight. Higher levels of chlorine addition generally resulted in material build-up (3,5,6).

Bromine (Br) and Iodine (I)--

Bromine and iodine are rarely encountered in cement kilns in significant quantities but can be expected to behave similarly to chlorine. Because of their volatility, bromine and iodine are not expected to occur in the clinker product. As with chlorine, the addition of bromine or iodine is expected to effect a slight reduction in clinker alkalinity.

Experiments have been conducted in Canada using waste oils containing up to 0.007 percent bromine relative to clinker production. Most of the bromine was retained in the process

solids with no change in clinker quality. Emissions from the kiln were approximately 0.7 percent of the bromine input with the waste oil (2).

Group VIII Elements

As far as is known, the Group VIII elements helium, neon, argon, krypton, and xenon, should have no effect on the manufacture and use of portland cement. Iron is discussed below.

Iron (Fe)--

Iron is present in all portland cement. Typical Fe_2O_3 clinker concentrations are 1-5 percent. Types II and IV portland cements are limited to Fe_2O_3 concentrations of 6.0 and 6.5 percent, respectively (10).

Transition Metals

Little is known of the effect of transition metals on cement manufacture. Titanium, zirconium, vanadium, chromium, molybdenum, manganese, cobalt, nickel, copper, zinc, cadmium, and mercury are discussed here. Most of the other transition metals are very rare and have not been studied in the cement system.

Titanium (Ti)--

Titanium is commonly found in cement raw mixes in concentrations of 0.1-1 percent as TiO_2. It apparently has little effect on the manufacturing process at these levels. Some evidence suggests that 1-2 percent concentrations of TiO_2 in clinker can improve cement strengths (16,33).

Zirconium (Zr)--

Zirconium is found in levels up to 0.5 percent in cement, probably as the oxide ZrO_2. The effects of higher concentrations are not well understood. It has little effect on cement quality at these levels although it may increase early strengths somewhat. Zirconium is probably not volatile in the kiln and is likely to remain in the clinker (7,34).

Vanadium (V)--

Vanadium is present in cement in levels up to 0.1 percent, presumably in its most highly oxidized state, V_2O_5. It apparently concentrates in the alite phase of the clinker and may increase the hydraulic activity of the alite at levels of about 1.5 percent V_2O_5. It may also increase the tendency of cement pastes to expand in sulfate solutions. Vanadium is sometimes found in high concentrations in crude oil and has been known to result in rapid refractory kiln lining deterioration. Vanadium is not likely to vaporize appreciably under the conditions found in cement kilns (7,9,20,35,36).

Chromium (Cr)--

Chromium is usually found in only trace amounts in cement clinker. Some chromium-rich cements have been reported to exhibit high early compressive strengths, improved burnability (at levels of one percent Cr_2O_3), reduced autoclave expansion, increased sulfate expansion, and accelerated cement hydration. Chromium is somewhat volatile and has been found in kiln dust in concentrations up to 1,000 ppm (7,16,20,23,27, 34,36,37, 38,39,40,41,42).

Molybdenum (Mo)--

Molybdenum has been reported in cement clinker in concentrations of 0.005-0.05 percent. Its effects on the manufacture and quality of cement are not known (7).

Manganese (Mn)--

Manganese is found in small concentrations in many raw materials used to produce cement, particularly slags. It has been known to result in unusually-colored cements and to increase the stability of certain cement phases, sometimes resulting in high early strengths. Manganese is unlikely to vaporize appreciably in cement kilns and is tolerable at fairly high concentrations (except in white cement). It has been reported in kiln dust samples in concentrations of about 150 ppm (9,16,37,43,44).

Cobalt (Co)--

Cobalt is usually found in cement in levels less than 0.01 percent. It is fairly stable and unlikely to volatilize in the kiln. Research indicates that cobalt can reduce the hydraulic activity of alite and increase clinker hardness. It is not known what levels of cobalt are tolerable in cement.

Nickel (Ni)--

Nickel generally occurs in cement clinker at levels up to 0.02 percent. Levels of 0.5 to 1.0% stabilize alite; up to four mole-percent of the CaO in alite can be replaced by NiO, which stabilizes the monoclinic form and apparently increases cement strengths at all ages. Water-soluble nickel salts are strong accelerators for cement hydration. Nickel is rather volatile and likely to concentrate in the kiln dust. Dust levels of nickel up to 1,000 ppm have been reported. Higher levels of nickel, such as the oxide NiO, appear to replace CaO resulting in increased strengths (7,9,16,20,27,41,47).

Copper (Cu)--

Copper is normally found in cement clinker at levels up to 0.05 percent. As little as two percent Cu_2O has been shown to inhibit alite formation. Soluble copper salts are known to retard cement hydration. It appears that high copper concentrations can be permitted provided an oxidizing atmosphere is

maintained in the kiln. Copper can be volatilized in the kiln and dust containing up to 300 ppm copper has been observed (7,16,23,24,48,49).

Zinc (Zn)--

Concentrations of zinc in normal cements can be as high as 0.2 percent. Zinc in the raw meal is known to improve burnability considerably and increase strength in levels of 1-2 percent. However, soluble zinc, Zn^{++}, will severely retard hydration. Tests in Canada using zinc-bearing waste oils found complete retention of zinc in the process solids at zinc loadings up to 0.01 percent (fuel plus raw feed zinc). Levels of zinc in stack dust as high as 0.5 percent have been found (7,16,23,24,42,49,50,51).

Cadmium (Cd)--

Few studies have been made on the effects of cadmium on cements. Cadmium has been found in kiln dust at a concentration of 4 ppm. The oxide, CdO, apparently increases burnability with little effect on hydraulic activity. High concentrations apparently decrease strengths (23,48,52).

Mercury (Hg)--

Little is known of mercury's behavior in cement kilns. It is likely to be extremely volative and has been detected in kiln dust in concentrations of 0.5 ppm. Mercury added to the clinker as an admixture is known to have little effect on strength but may be readily leachable from the concrete (23,52).

The Lanthanides

Elements 57-71 have similar properties and are referred to as "rare earth" or "lanthanide" elements. They are found as trace elements in cement but have not been studied in detail. The volatilities of the lanthanides in a cement kiln are expected to be very low and it is doubtful if they will concentrate appreciably in the kiln dust.

SECTION 5

RISK ASSESSMENT

The risks posed by the use of cement kilns to dispose of organic industrial wastes will depend on the adequacy of the engineering and procedural/operational controls exercised. Through the application of proper controls, it is probable that cement kilns can be used to dispose of large quantities of hazardous wastes with minimal risks to plant employees, communities adjacent to the plant, or the environment.

The demonstrated efficiency of cement kilns, even for destroying extremely stable hazardous wastes such as PCB's, indicates that as long as a waste is amenable to destruction in cement kilns and the rate at which it is introduced into the kiln is properly controlled, emissions will be significantly lower than levels achievable with conventional incinerator technology. The use of a well-engineered system for storing and pumping wastes along with the application of proper waste handling techniques will minimize the risks of accidential releases of waste materials into the environment.

To date, several types of wastes have been safely disposed of in cement kilns. Many industrial processes, including cement kilns, currently use waste fuels. However, these facilities are generally restricted to wastes with low toxicities. Cement kilns are typically constrained by regulatory authorities to using waste fuels containing less than two percent chlorine and negligible metal concentrations. Such waste fuels appear to present no significant risk of environmental damage.

The use of wastes containing toxic metals and high concentrations of chlorine, thus far has been restricted to experimental trials. These trials have been successful in disposing of highly toxic and stable wastes without incurring significant detrimental environmental impacts. Based on these results, it appears that many types of wastes, beyond those currently being used as fuels, can be safely disposed of in cement kilns as long as proper controls are applied.

This section addresses the risks of using waste fuels in cement plants by operational areas, specifically transportation, storage, handling, and kiln emissions. In each of these areas, potential problems and methods for mitigating risks are

discussed. The preparation of contingency plans to deal with possible plant emergencies involving hazardous wastes is also addressed.

TRANSPORTATION RISKS

Any waste that must be disposed of at a site other than its point of generation will require transport to the disposal site and will, during its transport, create a risk of spillage and/or fire. Such risks are not unique to a given method of off-site disposal and will be incurred whether the waste is to be disposed of by incineration, landfilling, or destruction in a cement kiln.

Although total transportation-related risks are unlikely to increase significantly if substantial amounts of wastes are redirected to cement plants, the resulting redistribution of risks may be a serious concern to impacted parties.

There are numerous combinations of truck, rail and barge usage which could be used depending on the geographic location of the waste shipper and the cement plant. It appears that most wastes supplied to cement plants for disposal are likely to be transported in tank trucks over public highways.

The transportation of hazardous wastes is regulated by the U.S. Environmental Protection Agency (40 CFR Part 263) and the U.S. Department of Transportation (49 CFR Part 177 for carriage by public highway). Compliance with these as well as other applicable Federal, State, and local requirements will serve to mitigate the risks involved in transporting hazardous wastes. In addition, plants utilizing waste fuels should exercise managerial procedures that further reduce risks to the public. Transportation-related issues that should be addressed in developing plans to use waste fuels include the selection of a reputable licensed waste hauler, the identification of most-favorable transport routing, and the enactment of thorough emergency contingency plans.

It is likely that cement plants, when contracting for waste fuels, will assign the responsibility for waste transportation to the waste supplier. Transportation risks will be the responsibility primarily of the waste hauler and secondarily of the employer of the hauler, in this case the waste supplier. Although the cement plant's legal responsibility for accidents occurring outside the plant grounds may be eliminated by such an arrangement, it is in the cement company's best interest to assure that exhaustive safety measures are implemented. Community acceptance of waste-fuel use may, in fact, be contingent upon guarantees of such safety measures. If the transportation

of wastes is handled by the waste supplier, the cement plant should assure that the supplier has given proper consideration to these transportation issues.

Prior to contracting for the delivery of waste fuels, the cement plant should investigate the credentials of a proposed waste hauler to assure that the hauler is in compliance with applicable licensing requirements, has a reputation for conscientious performance, and will abide by safety procedures established by the cement plant. A hauler's credentials and reputation can usually be verified through State hazardous waste management authorities or environmental protection authorities. Client references may also be obtained directly from the hauler and contacted to verify the hauler's past performance.

It is essential that emergency contingency plans be developed that include procedures for dealing with transportation accidents and that the waste hauler comply with the requirements of these plans. (Contingency plans are separately discussed later in this section.) The waste hauler is likely to already have measures in effect to deal with spill containment/cleanup. However, these plans should be reviewed to assure their adequacy and, if necessary, revised to reflect the particular needs of the program. It is also important that the hauler agree to abide by routing and scheduling plans formulated by the cement plant.

In planning for the delivery of wastes, care should be taken to route shipments so as to minimize potential public exposures from transportation accidents. This will involve the identification of alternative routes, assessment of roadway conditions, and the analysis of population exposures along alternative routes. The assessment of alternative routes is advisable whenever waste shipments will be moved on roadways other than principal routes of commerce or when wastes are to be transported in the vicinity of private residences or public gathering places.

A principal concern in evaluating transport routes is likely to be the number of private residences along the proposed routes. Alternative routes should also be assessed to determine relative safety features, such as the condition of road beds and the adequacy of traffic controls. Waste shipments should be arranged to avoid periods of traffic congestion and regularly-scheduled public gatherings such as schools or religious services along the route chosen.

Typical tank trucks will have a capacity of about 45,000 pounds or 5,000 gallons. Assuming an average waste-fuel heating value of 10,000 BTU per pound or 90,000 BTU per gallon, it is possible to calculate the number of shipments required for various levels of waste fuel utilization.

Shippage rates can also be used to estimate the probability of an acidential waste spill. Based on historical accident rates in the United States, the probability of a transportation-related accident resulting in a spill causing more than $100 in property damage is:

$$P = 9.25 \times 10^{-7} N \qquad (2)$$

where P is the probability of such an occurrence and N is the total number of miles travelled (53).

STORAGE AND HANDLING RISKS

The storage and handling of waste fuels at cement plants entails risks similiar to those encountered by many industries which use or generate flammable or toxic materials. Techniques commonly employed to mitigate such risks are well-developed and can be applied with minimal modification to the storage and handling of waste fuels at a cement plant. The use of such equipment and procedures will result in negligible risks of on-site spills, fires, or worker exposures. Comprehensive emergency contingency plans will further minimize the chances of personal injury or property damage resulting from an accidental occurrence.

Storage and handling requirements will differ according to the characteristics of the waste being used. Variables to be considered in selecting appropriate equipment and handling methods include the waste's toxicity, flamability, corrosivity, reactivity, vapor pressure, viscosity, and solids content. In the following discussions of risk mitigation measures, it is assumed that the wastes being utilized possess characteristics such that the handling and storage systems used should prevent any release of wastes or waste vapors into the environment.

Although a storage/handling system can be reasonably designed to emit essentially no waste materials during normal operations, small spills may occur in the tankage and pump areas as the result of equipment failures, maintenance operations, and tank loading operations. Through the use of well-designed systems and procedures, these small spills can be limited to rare occurrences and dealt with in a timely and effective manner to eliminate the risk of injury or property damage.

The principal environmental concerns in the storage and handling of waste fuels are the risks posed by material spills and fires. A spill of waste fuel could result in the contamination of soil, ground water or surface water, and the release

of hazardous vapors. The additional risks associated with waste fuel fires are those of property damage, personal injury, and the gross contamination of air with combustion products.

All storage tanks used for storing waste fuels should be of sturdy and leak-proof construction in accordance with regulations set forth by the Occupational Safety and Health Administration (29 CFR Part 1910, Subpart A, section 1910.106). The use of a plant's existing storage tanks, pumps, and piping may be feasible. However, the compatability of the wastes with existing equipment should be assessed to insure that excessive corrosion, pumping difficulties, or vapor releases do not occur.

A principal concern in selecting equipment will be the corrosiveness of the wastes to be handled. Material made of steel may be appropriate for handling some wastes while more corrosive wastes may require fully lined systems. Equipment suppliers will be the best source of information for matching equipment specifications to waste characteristics. Special care should be exercised in selecting pump systems. Waste fuel pumps will typically be required to handle wastes of varying viscosities with occasionally high solids concentrations, and to deliver variable flow rates with high pressures (about 100-200 psi) for long piping distances.

Waste-fuel storage tanks and pumps should be located on impermeable pads and surrounded by dikes, berms, or similar structures capable of containing the results of any massive spill. Emergency equipment, such as fire extinguishers, breathing masks, sorbent materials, and shower-wash stations, should be sited in the immediate vicinity of the storage area, and employees trained in their proper use.

Off-loading of tank trucks or tank cars should be conducted in a way that minimizes vapor releases into the air. The vapors present in the plant's storage tank will be displaced as the tank is filled and should be properly contained. These fumes can be easily returned to the transport tank via a closed line between tank vents. In addition, sorbent traps should be present on the plant's storage tank vents to contain vapors evolved as a result of thermal expansion and molecular diffusion during normal storage.

As an alternative to sorbent traps, a plant may elect to vent tank vapors directly into the kiln's feed air supply. This technique is sometimes used in lime kilns and kraft pulp mills to control vapor emissions and odors. Such systems generally function under negative pressure and are designed to keep vapor concentrations well below one-quarter of the vapor's lower explosive limit. However, if such a system is relied upon

for compliance with applicable regulations, a backup system must also be available for containing emissions when the kiln receiving the vapors is not operating.

To eliminate spillage and worker exposure during maintenance operations and after transfer of wastes between tanks, a system for flushing waste residues from piping, pumps, and tanks should be employed. One possible system is illustrated in Figure 4. Using such a system, equipment containing waste materials can be selectively rinsed with a relatively harmless substance such as No. 2 fuel oil. A valving system similiar to the one illustrated can be employed to direct the rinse oil through all piping containing waste fuels, the transfer hose used to drain the tank truck, the waste-fuel pump, and the waste-fuel storage tank. This will allow refueling and maintenance operations to be conducted without risking spills, vapor releases, or worker exposures. As an added precaution, piping should be arranged to allow the system to be drained by gravity flow.

Automated monitors should be employed to alert operators in the event of a waste-fuel handling problem. These systems may even be designed to institute proper corrective actions. A pressure transducer located in the waste piping at the entrance into the kiln can be employed to automatically turn off the waste fuel pump in the event of a sudden pressure drop as would be experienced in a pipe rupture or pump failure. Interlocks should also be provided to automatically stop the flow of waste fuels if either normal fuel supply or the combustion air flow are interrupted.

Monitoring systems capable of detecting organic vapors can be placed at key locations to signal accidental waste-fuel leaks. Automated systems such as portable gas chromatographs or organic carbon detectors capable of detecting trace emissions may be appropriate if toxic vapors could be released by waste spills.

All storage and handling equipment should be subjected to thorough visual inspection during each operating shift. Training should be conducted for all employees required to interface with waste-fuel operations. These personnel should be familiar with all equipment and operating procedures, be able to identify process excursions and failures, and be well-versed on corrective actions.

The use of appropriate equipment and operating procedures as described in this sub-section should serve to reduce the risks incurred in storing and handling waste fuels to acceptable levels. As these controls are adopted to the specific needs of individual programs, the basic premise employed in their development (i.e., essentially eliminating all storage and handling emissions) should be maintained. Although such

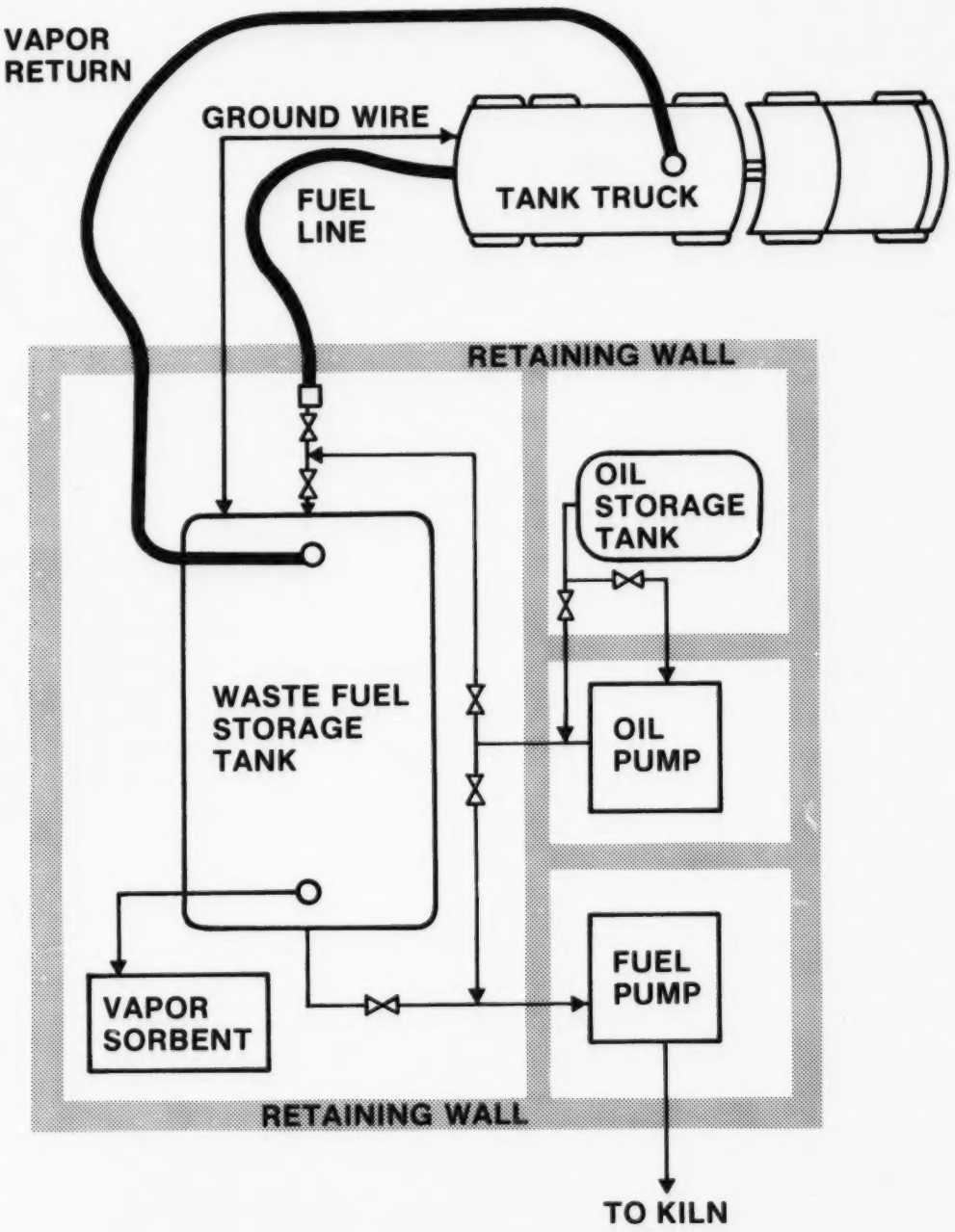

Figure 4. Waste Fuel Storage and Handling System.

controls may be more stringent than requirements currently imposed by law, they may be necessary in order to obtain community approval of a proposed waste-fuel program and are likely to be in the best interests of all involved parties.

KILN EMISSIONS

The risks posed by emissions from cement kilns utilizing waste fuels will vary with several factors. These include the characteristics of the wastes used, the rate of waste injection into the kiln, existing kiln chemistry, the efficiency of the particulate control devices employed for cleaning stack gases, and the disposition of the collected kiln dust.

Because the work to date in characterizing emissions has involved only chlorinated wastes and waste lubricating oils, detailed discussions of emission characteristics in this section are limited to these waste types. The potential fates and effects of numerous possible waste materials are addressed in Section 4 of this report.

Stack Emissions

Wastes injected into a cement kiln will typically experience peak temperatures in excess of 2600°F (1430°C) and residence times of about 10 seconds. In addition, the solid and volatilized materials normally present in the kiln are extremely basic and act as an effective "scrubbing" system in removing any acids formed during waste combustion. This scrubbing action has been shown to be quite effective in removing free chlorine and hydrochloric acid residues generated by the use of chlorinated waste fuels.

The efficiency of waste destruction demonstrated in cement kiln waste-fuel experiments indicates that even extremely stable and highly toxic materials can be safely disposed of in cement kilns. The levels of destruction efficiency achieved in cement kilns are significantly higher than those routinely encountered in chemical waste incinerators.

Under proposed Resource Conservation and Recovery Act (RCRA) standards, hazardous waste incinerators will be required to destroy a minimum of 99.99 percent of the principal organic hazardous constituents of the wastes being burned (Federal Register, January 23, 1981, page 7666). This destruction efficiency is calculated by the following formula:

$$DE = 100\ (W_{in} - W_{out})/W_{in} \qquad (3)$$

where : DE = destruction efficiency

W_{in} = mass feed rate of principal toxic components of waste going into the incinerator

W_{out} = mass emissions rate of principal toxic components in waste in the incinerator combustion zone.

Table 4 lists the minimum destruction efficiencies found in the most recent tests conducted using chlorinated wastes (5,6). Also presented in Table 4 are the maximum residual emission levels from those tests. In most cases, residual waste concentrations detected during experiments were below analytical detection limits. In these instances, efficiencies were calculated on the assumption that emissions were equal to the lowest detectable concentrations.

Based on these results, it appears that essentially complete destruction of most organic materials can be achieved in cement kilns. However, a potential exists for the formation of trace quantities of organic chlorides as the result of burning chlorinated wastes.

TABLE 4. MINIMUM DESTRUCTION EFFICIENCIES ENCOUNTERED IN A CEMENT KILN

Waste	Destruction Efficiency (Percent)	Maximum Emissions (Percent of Input)
RCRA Standard	99.99	.01
Dichloromethane	99.995	.005
Trichlorobenzene	99.9998	.0002
PCB	99.99998	.00002
Chlorophenols	99.99999	.00001
Phenoxyacids	99.99998	.00002
Freon	99.99986	.00014

Note: None of these wastes (except Freon) were actually detected in stack emissions. Efficiencies were calculated assuming emissions equal to the lowest concentrations detectable.

Source: Ahling, B., "Combustion Test With Chlorinated Hydrocarbons in a Cement Kiln at Stora Vika Test Center," Swedish Water and Air Pollution Research Institute, March 16, 1978.

Canadian and Swedish experiments have identified three daughter molecules during stack testing, specifically, chloroform, dichloromethane, and carbon tetrachloride. Although these compounds also were detected in stack emissions during periods when no waste fuels were being used, the highest concentrations were found when chlorinated waste fuels were added. It appears that contamination of plant feed water during these experiments could have resulted in most of the emissions detected.

Table 5 presents the maximum and average concentrations of organochlorides actually detected during the Swedish and Canadian experiments. Also presented are ambient concentrations of these compounds over land masses as revealed by several studies conducted throughout the world.

Because global background levels of carbon tetrachloride are considerably greater than stack concentrations detected during any waste-fuel experiments, it appears that carbon tetrachloride emissions from cement plants burning waste fuels are not a significant concern.

Emissions of chloroform do not correlate well between the Swedish and Canadian studies. The Canadian studies revealed peak background chloroform concentrations when no waste fuels were being burned which are approximately 1,500 times lower than the Swedish background emissions. This large difference indicates that the relatively high emissions detected in the Swedish experiments (as compared to the Canadian results) probably originated from contamination of the feed water used in mixing the raw meal being fed into the kiln.

If the emissions detected during the Canadian tests are assumed to be typical, chloroform emissions will not be a significant concern. No perceptible change in off-site ambient concentrations of chloroform is likely to be detectable from such low-level emissions.

The dichloromethane emissions detected during the Canadian experiments may also have been caused by feed water contamination. The highest background concentrations of dichloromethane detected when no chlorinated wastes were being injected into the kiln (18 ppb) were higher than the average estimated emissions when burning waste fuels (14 ppb).

More work should be conducted to characterize background emissions of dichloromethane and their relation to the use of chlorinated waste fuels. Emissions in the amounts detected during the Canadian tests are unlikely to significantly impact off-site areas. Even very minimal dispersion of such low-level emissions is likely to reduce plume concentrations to below average ambient levels.

TABLE 5. ORGANOCHLORIDE EMISSIONS (a)

Contaminant	Maximum Emissions With Waste Fuels	Maximum Emissions Without Waste Fuels	Average Emissions With Waste	Average Global Background
Chloroform (b)	52	27	12	
Chloroform (c)	0.069	0.018	0.041	0.015
Dichloromethane (c)	29	18	14	0.036
Carbon Tetrachloride (c)	0.006	0.004	0.003	0.120

Notes: (a) All concentrations are expressed in parts per billion (ppb). To convert into micrograms per cubic meter (ug/m^3) the following conversion factors should be applied:

ppb Chloroform x 5.0 = ug/m^3
ppb Dichloromethane x 3.5 = ug/m^3
ppb Carbon Tetrachloride x 6.4 = ug/m^3

(b) Emission levels taken from Swedish experiments.
(c) Emission levels taken from Canadian experiments. Neither dichloromethane nor carbon tetrachloride were detected during the Swedish experiments.

Sources: Ahling, B., "Combustion Test With Chlorinated Hydrocarbons in a Cement Kiln at Stora Vika Test Center," Swedish Water and Air Polluting Research Institute, March 16, 1978.

Mac Donald, L.P., et. al., "Burning Waste Chlorinated Hydrocarbons in a Cement Kiln," Fisheries and Environment Canada, March, 1977.

"Chloroform, Carbon Tetrachloride, and Other Halomethanes: An Environmental Assessment," National Academy of Sciences, 1978.

Because cement kilns have demonstrated destruction of extremely stable wastes such as PCB's to beyond the limits of analytical detection, it is unlikely that compounds such as those in Table 5 could have escaped destruction. It is likely

that these compounds are formed from the components of fractured waste molecules, or that they originate from contamination of the feed water used to manufacture the clinker.

It is known that the incineration of chlorophenols can result in the emission of dioxins or furans which may be extremely toxic. For this reason, Swedish researchers conducted sensitive monitoring for these compounds during the three trials in which chlorophenols were used as waste fuels. In one of these trials, trace amounts of what may have been heptachlorodibenzo-p-dioxin (7CDD), octachlorodibenzo-p-dioxin (8CDD), or octachlorodibenzofuran (8CDF) were detected. Mass spectrometric analysis to confirm the identity of the compounds detected was not possible as the concentrations present were too low. As the generation and survival of these compounds in a cement kiln cannot be ruled out, it is advisable that further experimental work be conducted before wastes with a potential for generating dioxins or furans are allowed to be burned in cement kilns on a routine basis.

As described in Section 4 of this report, the introduction of chlorine into a kiln system will result in increased particulate loadings in the kiln exhaust gases. The chlorine released when chlorinated wastes are broken into their constituent elements will form volatile alkali chlorides which exist as gaseous fumes at normal kiln burning zone temperatures. These alkali chlorides, principally potassium chloride and possibly sodium chloride, will condense to dusts at the lower temperatures encountered outside the kiln and must be removed by the plant's dust collection equipment.

Dry cement kilns utilizing suspension preheaters are likely to experience material buildup or ring formation problems when burning chlorinated wastes and are, therefore, unlikely candidates for using this type of waste fuel. Kilns which recycle a significant portion of the collected kiln dust may also encounter similar problems.

The amount of excess kiln dust formed when burning chlorinated wastes will probably be in direct stoichiometric proportion to the amount of chlorine present in the wastes. Assuming that all chlorine reacts to form potassium chloride, up to 2.1 pounds of additional kiln dust will be generated for every pound of chlorine injected into the kiln. For an estimated maximum chlorine addition rate equal to 0.6 percent of clinker production, collection system dust loadings could be expected to increase by up to 25 pounds of dust per ton of production capacity. Because dust formation rates are likely to be linked to the alkali content of the plant's raw feed materials, dust loadings and particulate emissions may vary considerably between plants.

In plants which routinely add chlorine to the kiln to reduce clinker alkali content, the use of chlorinated waste fuels should present no additional dust emission problems. Other plants, however, will experience additional dust collection system loadings which may result in increased stack emission of particulates.

The ability of control equipment to capture the additional dust generated when using chlorinated waste fuels is expected to vary greatly between cement plants. Plants already experiencing problems meeting applicable particulate emission standards are unlikely to be able to prevent further deterioration of their emissions and are, therefore, unlikely candidates for using such waste fuels. Plants which have excess dust collection capability and are operating below allowable particulate emission levels are much more suitable candidates for using chlorinated waste fuels. However, even plants which are marginally in compliance could potentially use chlorinated waste fuels without exceeding emission standards. Several process modifications could probably be employed to maintain acceptable emission levels. These include reducing insufflation rates of recovered dust, reducing the rates at which leached dust is recycled, altering kiln drafts, and modifying kiln combustion kinetics.

Canadian experiments with used lubricating oils have shown excellent potential for the use of such wastes in cement kilns. During these experiments, mass balances were conducted on the major contaminants of the oils, lead, zinc, bromine, and phosphorus. The average concentrations of these elements in the oil and their rate of addition relative to clinker production are shown in Table 6.

The amounts of phosphorus and zinc input with waste fuels were relatively insignificant in relation to their concentrations in the raw meal used to produce the clinker. Their presence in such low amounts in waste fuels, therefore, presents no significant environmental risk.

Bromine appears to act in a manner identical to chlorine in a kiln system. Bromine from a waste fuel forms volatile alkali bromides which enter the exhaust gas stream and must be removed by the kiln's dust collection equipment. The amount of bromine introduced into the kiln during this experiment was probably two orders of magnitude (about 100 times) lower than the quantity required to produce significant particulate emission problems.

Lead emissions in the kiln exhaust gases did not increase as a result of waste oil burning. The lead was largely retained in the cement clinker. Some of the lead from the waste oils was deposited with the collected kiln dust. As long as

particulate emissions are reasonably under control, it appears that lead may be safely introduced with waste fuels in amounts up to 0.02 percent of the clinker production rate. The disposition of lead when introduced at higher rates should be thoroughly investigated before its routine use is allowed.

TABLE 6. WASTE OIL CONSTITUENTS

Element	Average Concentration in Waste	Maximum Rate of Addition
Lead	0.6%	0.02%
Bromine	0.15%	0.007%
Zinc	0.1%	0.01%
Phosphorus	0.1%	0.06%

Note: Maximum rate of addition is the weight of each element added relative to clinker production. It includes amounts of the element input with the raw meal.

Source: Berry, E.E., et. al., "Experimental Burning of Waste Oil as a Fuel in Cement Manufacture," Environment Canada, June, 1975.

DUST DISPOSAL

Dust disposal problems may be increased by the use of waste fuels. However, the proper management of disposed dust will effectively minimize the risk of any resulting environmental damages. The environmental effects of changes in dust composition are not well understood and should be researched before allowing cement plants that do not contain runoff and leachate from dust disposal areas to use toxic waste fuels.

The chlorine content of discarded dust was found to increase from normal levels of about one percent chlorine to levels as high as seven percent when using chlorinated waste fuels. In addition, potassium oxide concentrations were found to increase slightly and total sulfur concentrations to decrease (3).

Only one instance has been observed in which organic contaminants were found in kiln discard dusts. During the three Swedish experiments using PCB's, one dust sample was found to contain approximatelg 0.005 percent tetrachlorobenzene (6). It is very unusual that tetrachlorobenzene was detected and not more stable penta-or hexachlorobenzene. It does not appear likely that the tetrachlorobenzene survived the hostile kiln environment. However, future research with toxic wastes should investigate the potential for kiln dust contamination.

Slight changes in the lead and bromine concentrations of discarded kiln dust occurred when waste oils were burned in the Canadian experiments. Lead concentrations increased from an average of about 0.03 percent to a high of 0.44 percent. Bromine concentrations increased from approximately 0.3 percent to a high value of 1.5 percent (2). Such changes could potentially affect the status of discarded kiln dust under Resource Conservation and Recovery Act (RCRA) hazardous waste regulations. At this time, cement kiln dusts are specifically excluded from most RCRA requirements until further characterization studies are completed by EPA's Office of Solid Waste.

Under the RCRA standards for identifying hazardous wastes (40 CFR Section 261.24), an Extraction Procedure (EP) test would be applied to cement kiln dust to determine if it is subject to regulation as a hazardous waste. The degree to which lead and other potential contaminants could be leached from the kiln dust both in the EP test and through natural weathering should be determined through further research.

Very little work has been conducted to determine the environmental risks presented by the disposal of cement kiln dust. Until more is known concerning leachate characteristics, precautions should be taken to avoid potential contamination of ground water and surface water from dusts generated when burning waste fuels. It is recommended that any plant using waste fuels having toxic components, completely contain runoff and infiltration from discarded kiln dust disposal areas.

PROCESS MONITORING

Before cement plants are allowed to routinely burn hazardous waste materials, monitoring devices capable of assuring the environmental adequacy of the burning operations should be identified. Appropriate systems for cement kilns using toxic waste fuels may include particulate monitors, oxygen monitors, temperature sensors, and hydrocarbon monitors. The amount of information now available concerning process variables is insufficient to permit the identification of adequate monitoring systems. Further research should be conducted to identify the simplest monitoring techniques that can be used to effectively insure the safety of waste fuel operations with toxic materials.

A system capable of detecting stack particulate emissions on a continuous or semi-continuous basis would be appropriate for some waste fuels. Plants burning wastes that could significantly increase particulate emissions or result in the emission of toxic particulates should probably employ such a system.

When burning toxic materials it is advisable to monitor kiln exhaust gases to assure the presence of sufficient excess oxygen. Many kilns are already equipped with this type of monitor. Temperature monitors already employed in cement kilns may also be sufficient for assuring steady burning-zone temperatures, provided that monitor response times and sensitivities are acceptable.

When burning highly toxic materials, equipment capable of detecting trace amounts of unburned hydrocarbons may be appropriate. If employed, such a system should be capable of detecting concentrations of organic materials sufficient to demonstrate compliance with RCRA destruction efficiency standards for incinerators.

EMERGENCY PLANNING

Detailed emergency contingency plans should be prepared for dealing with potential accidents at the cement plant and during transport of the wastes to the plant. These plans should also be incorporated into the design of waste handling systems. The basic purpose of contingency plans is to identify appropriate response scenarios for plant personnel in the event of potentially serious incidents.

Waste storage and handling areas should be arranged to allow rapid emergency access for fire trucks and spill clean-up teams. Operating personnel should be familiar with the response appropriate to incidents which could result in unacceptable risk levels.

Planning efforts should be thoroughly coordinated with appropriate emergency response units such as fire departments, police, and hospitals. It should be ascertained that adequate capabilities are available for dealing with potential accidents. Medical assistance and fire fighting units should be kept informed of the nature and quantities of flammable and toxic materials stored at the plant.

Responsibility for initiating and coordinating emergency response activities should be clearly delegated. This authority should be assigned to a sufficient number of individuals so that at least one designated emergency coordinator is present at all times.

SECTION 6

ECONOMICS OF WASTE FUEL USE

This section examines the economic feasibility of burning industrial wastes in cement kilns. From the cement industry's viewpoint, before expenses for burning wastes can be incurred, there must be a reasonable assurance of an increased profit or reduced costs to the company. This analysis found that the cement industry is financially healthy although there is great competition for money to institute improvements. The amount of money required to equip a plant for industrial waste burning is only a few cents annually per ton of cement produced. There is a great potential for a substantial return on such an investment.

CEMENT INDUSTRY DESCRIPTION

The cement industry in the United States consists of 49 companies with 158 plants and 342 operating kilns. Plant locations are shown in Figure 5. The plants vary in capacity from 55,000 tons per year (TPY) to 2,400,000 TPY. There is a trend upward because larger plants tend to be more efficient and have lower capital costs per ton of production capacity. From 1950 to 1975, the average plant capacity increased from 335,000 TPY to 536,000 TPY.

Economic Characteristics

Rate of Return--

The Portland Cement Association reports that the average annual rate of return (net income after taxes as a percentage of net worth) fluctuated over the last 30 years from over 20 percent in 1955 to about 6 percent in 1970 (54). The most recent data from the association is given in Table 7. This data shows an upward trend from 1975-1977. In a recent survey of the industry, Value Line Investments found that the improvement continued during 1978 and 1979 (55).

The cement industry is very capital intensive, operates with a high overhead and is largely dependent on the construction industry. With the current depressed construction market, the rate of return should be reduced. However, Value Line is predicting that the 1980 rate of return will be on a par with 1978.

Figure 5. Portland Cement Plants by Producing Capacity.

TABLE 7. PERCENT RETURN ON NET WORTH

Year	Percent Return
1972	7.4
1973	9.9
1974	8.8
1975	7.1
1976	9.8
1977	13.0

Source: Portland Cement Association, March 1978.

Projected Capital Requirements--

The industry has required substantial capital in the past and projects large near-term (5 year) requirements. Table 8 shows the industry's capital requirements for the 1976-1985 period as estimated in 1978. It should be noted that the projected estimate for 1981-85 assumed a 5 percent annual inflation rate. With our existing knowledge of inflation, a rate of 10 percent is probably more accurate. This would change the 6.15 billion dollar estimate to about 7.95 billion dollars for the remaining needs (1981-1985).

According to the Economic Research Department of the Portland Cement Association, financing for past capital projects in the cement industry has depended heavily on internally generated funds (retained earnings and depreciation) as well as debt issues. The industry will probably continue to rely on its internal cash flow and the debt market as the primary sources of new capital.

Energy Costs--

Energy costs normally amount to 33 to 40 percent of the total cost of cement manufacture but may be a high as 65 percent. Electrical power usually represents a significant portion of these energy costs. Increasing energy costs and fears of supply interuptions have motivated the industry to increase its energy efficiency and to accelerate plant conversions to coal.

Energy efficiency improvements since 1950 are shown in Table 9. The amount of energy used to produce a ton of cement has steadily fallen since that time. In 1950, 7.75 million BTU's were required per ton of product. It was estimated in 1978 that only 6.1 million BTU's or less would be required per ton by 1979.

TABLE 8. CAPITAL REQUIREMENTS OF THE U.S. CEMENT INDUSTRY, 1976-1985

Capital Requirements	Cost ($Billion)
New Capacity Additions	$1.00
Replacement and Modernization of Plants Built Before 1946	0.74
Process Conversion and Modernization from Wet Process to Dry Process	2.15
Modernization of Existing Dry Process Capacity	0.75
Total for 10-year Period	4.64
Work in Process 1976-1980	0.29
Remaining Needs 1981-1985 (stated as 1976 dollars)	$4.35
Remaining Needs 1981-1985 - Restated to Reflect 5 % Annual Inflation Rate Over 10-year Period (assuming 1981-1985 needs are spread equally over 5 years)	6.15 (7.95)*
Work in Process 1976-1980	0.29
Total Capital Needs 10-year Period	$6.44 (8.24)*

Note: *Figures in parentheses are based on a 10 percent annual inflation rate versus 5 percent.

Source: Portland Cement Association, "The U.S. Cement Industry: An Economic Report," 1978.

The industry's energy improvement measures have mitigated recent energy cost escalations to some extent. However, the cost for energy still continues to rise at a rapid pace.

Cement plant coal conversions, initiated in the early 1970's reversed the earlier trend away from coal shown in Table 10. In 1972, 39% of production was with coal. The Portland Cement Association estimated that this figure may reach 90% by 1980; Value Line recently estimated that coal use will be about 80% in 1980.

TABLE 9. TRENDS IN ENERGY COSTS AND ENERGY EFFICIENCY IN THE CEMENT INDUSTRY

Year	Energy Requirement (Million BTU/Ton)	Energy Cost ($/Ton)
1950	7.75	-
1955	7.72	4.16
1975	6.58	9.34
1976	6.30	-
1977	-	12.50
1979 (Estimate)	6.10	15.00

Sources: Portland Cement Association, March 1978; Energy Handbook, Van Nostrand Reinhold, 1978.

TABLE 10. TRENDS IN USE OF COAL IN THE CEMENT INDUSTRY

Year	Coal as a Percent of Energy
1955	51
1972	39
1976	55
1980	80/90*

Note: *80% is the 1980 Value Line estimate; 90% is the 1978 PCA estimate.

Sources: Portland Cement Association, March, 1978 and Value Line Investments, New York, 1980.

Organic industrial wastes burned in cement kilns will reduce fuel costs. Contacts with cement manufacturers indicate that a few plants have been using waste fuels for some time to supplement their fuel needs. Some plants have successfully used waste fuels for up to 100 percent of their kiln fuel needs for short periods. However, waste fuels have typically been used as a supplement to reduce normal fuel use. The amount of waste fuel that may be used at a particular plant depends primarily on the characteristics of the waste and the ability of the plant to store and pump wastes in the required quantities.

Manufacturing Processes

Two processes, wet and dry, are used in making cement. They are similar except that in the wet process the crushed and proportioned raw materials are ground, mixed with water and fed into the kiln in the form of a slurry. In the dry process raw materials are fed into the kiln in a dry powder form. Production capacity is currently divided about equally between the two processes. However, because the dry process is more energy efficient, almost all new plants and modernizations use the dry process. Table 11 presents a summary of U.S. cement manufacturing capacity by process type as well as kiln age.

TABLE 11. KILN AGE AND PROCESS SUMMARY

Year Built	Wet Process			Dry Process		
	No. Kilns	Clinker Capacity	Average Capacity Per Kiln	No. Kilns	Clinker Capacity	Average Capacity Per Kiln
1976	1	150	150.0	13	7,259	558.4
1971-1975	11	4,460	405.5	25	11,772	970.9
1956-1960	26	5,767	360.4	8	3,018	377.3
1951-1955	31	5,590	180.3	23	3,730	162.2
1946-1950	28	4,860	173.6	15	2,115	141.0
1941-1945	5	649	129.8	1	92	92.0
1936-1940	6	1,466	244.3	2	264	132.0
1931-1935	1	154	154.0	2	314	197.0
Before 1931	28	3,257	116.3	11	1,103	100.3
Total	191	45,756	239.6	151	43,398	287.4
AVERAGE Kiln Age (Years):						
Based on Number of Kilns			27			21
Based on Clinker Capacity			22			15

Source: Market and Economic Research, Portland Cement Association, December 31, 1979.

Transportation

The availability of modes of transportation for shipment of industrial waste to a cement plant can have a bearing on the cost of utilizing waste fuels. Analysis of the modes of transportation used for shipping cement yields some useful data. Cement production stated in terms of percent of shipment by transportation mode is shown in Table 12.

TABLE 12. CEMENT SHIPMENT SUMMARY

Mode of Shipment	1950	1975
Rail	75%	13%
Water	1%	1%
Truck	24%	86%
Total	100%	100%

Source: Portland Cement Association, March 1978.

Because of the lower cost of water transportation per ton, this mode is attractive to cement manufacturers if available. From Table 12 it may, therefore, be assumed that such transportation is available only to a small number of plants for shipping cement. A 1977 report for the National Association of Cement Shippers estimated that rail was used for twice as many inbound shipments as outbound cement shipments (56). Hence, about 25 percent of the cement plants are estimated to have rail service available. The average plant is therefore, assumed to have only truck transport available for bringing in industrial waste.

Engineering Controls

The burning of industry wastes in a kiln may significantly increase the particulates to be collected from the kiln exhaust gas. Current EPA air pollution requirements equate to a collection device efficiency of about 99.88%. Table 13 shows the results of a 1975 survey of types of kiln dust collection systems in use.

Industry personnel have speculated that electrostatic precipitators probably will be used in the design of most future cement plants and modernizations. They advised that precipitators, in combination with certain other systems, generally allow them to meet existing Federal and State air pollution control standards for particulates.

It is assumed in the subsequent case study that no additional air pollution control costs are incurred as the result of waste fuel use. However, actual operating and maintenance costs may increase if halogenated waste fuels are used.

WASTE SPECIFICATIONS

The specifications established for wastes accepted for burning will have a distinct effect on cost. A waste which is low in heating value and considered hazardous is a serious problem to the generator who will normally have to pay for its disposal.

TABLE 13. DISTRIBUTION OF KILN DUST COLLECTION SYSTEMS IN WET AND DRY PROCESS CEMENT PLANTS

Kiln-Dust Collection System	Number of Plants	
Single Dust Collectors	Wet Process	Dry Process
Cyclones	2	2
Precipitators	31	3
Baghouses	3	3
Wet scrubbers	1	0
Settling chambers	1	0
Combinations of Dust Collectors		
Precipitators and wet scrubbers	1	0
Cyclones and wet scrubbers	1	0
Cyclones and precipitators	14	12
Cyclones and baghouses	4	16
Cyclones, baghouses, and precipitators	2	2
Baghouses and precipitators	1	1
Baghouses and wet scrubbers	0	1

Note: Data is from a survey of 101 U.S. cement plants.

Source: Davis, T.A., and D. B. Hooks. "Disposal and Utilization of Waste Kiln Dust from Cement Industry," EPA-670/2/75-043, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975.

On the other hand, a waste which is high in heating value and relatively free of hazardous compounds may have a positive value to the waste generator. The cement plant will be most concerned, however, with the reliability of its supplies. Off-specification wastes or intermittent availability could be serious impediments to a plant's attempts to institute a waste fuel program.

Heating Value

The primary benefit of using waste fuels is the reduction in the use of regular fuel use realized. In recent tests of burning wastes in kilns, the average waste had heating values of 94,600 to 117,800 BTU/gallon. This compares with a value for No. 6 fuel oil of about 138,000 BTU/gallon. The heat content recovered when using a waste fuel can be expected to vary depending on the waste constituents. Heat recovery has

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been reported to range from near 100 percent for a waste oil to about 65 percent for a waste containing 40 percent chlorine by weight.

Chemical Content

One of the most promising uses of cement kilns appears to be in the destruction of chlorinated wastes. Chlorinated waste solvents, such as methylene chloride, chlorotoluene, and perchloroethylene, are used in large quantities by industry. A substantial portion of these solvents are of sufficient purity to allow their redistillation by the waste generators or disposal firms. It appears that only the low purity solvents (those containing about 20% chlorine by weight or less) will be available for use in cement plants.

To produce low-alkali cements, many cement plants must attempt to vaporize a portion of alkalies in their kiln feed. This can be achieved by the addition of chlorine to the feed materials which joins with the alkali to produce volatile alkali chlorides. When waste products containing chlorine are burned, the chlorine in the wastes is released and combines with the alkali to achieve the same end result. Plants which currently use chloride addition to reduce clinker alkali content could readily convert to the use of chlorinated waste fuels.

The rate of chlorinated waste use is restricted by the ability of a plant to pass the chlorine through without experiencing material build-up problems, ring formation, or unacceptably high particulate emissions. Chlorine tolerances of cement plants will probably vary according to the amount of alkalies present in the plants' feed materials. Assuming adequate control of emissions, chlorine input rates are likely to be restricted to about 0.6 percent by weight of the clinker production in typical U.S. wet-process kilns. (Dry kilns begin experiencing problems at levels at low as 0.015 percent). A waste fuel containing 20 percent chlorine by weight and having a heat of combustion of 10,000 BTU per pound could probably be used to supplement from 7.5 to 10 percent of a wet kiln's fuel requirements. As the chlorine content of the waste is decreased the amount of waste fuel that can be used is increased.

At this time, very stable compounds such as polychlorinated biphenyls (PCB's) have not been included in waste burning operations other than research projects. The temperature and residence time in a cement kiln far exceeds those required by Federal regulations for PCB incineration. However, due to the negative association that PCB's have for the general public, their use could create problems with nearby communities. After a period of time of demonstrated good operation with less toxic wastes, an effort might be undertaken to educate neighboring

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communities to accept more toxic materials. Similar problems may be encountered with wastes containing significant levels of heavy metals and other toxic materials.

Toxicity, Reactivity and Corrosivity

Higher toxicity wastes will normally bring higher revenues to a cement plant. However, public opposition could be more important than purchase price. There will be cases when such wastes will be appropriate for the kiln operator to accept for destruction. However, these burns should be limited to reasonably small quantities and for short periods until a sufficient degree of experience is achieved to assure the safety of the operation.

Reactivity is the characteristic of a material which causes it, under certain conditions, to react with another element or compound to produce heat, gas, vapor or any dangerous end product. Care must be taken that wastes which will react adversely are not combined at the cement plant. Problems arising from waste incompatability can be minimized by quality control sampling and flushing of the equipment with fuel oil between waste burns.

Storage tanks, pumps, and piping must be resistant to the degree of chemical corrosion expected. Unless appropriate equipment is available, extremely corrosive wastes and those which contain solids which may pit the pump and impeller should not be accepted.

Viscosity, Specific Gravity and Solids Content

These three waste characteristics are necessary concerns in the design and costing of the waste transfer and burner system. The weight and viscosity must be established within reasonable limits before the pump and burner are selected.

The variable viscosity of waste fuels will generally preclude the use of existing fuel oil pumps. Fuel oil pumps are usually designed to handle liquids of a very limited viscosity range. The amounts of sediment and gritty materials expected in waste fuels will also preclude the use of most fuel oil pumps.

Settleable solids may be settled out in storage tanks and drawn off for separate disposal. This adds to the original facilty cost and also to the operating costs if the sludge must be disposed of separately. Most plants are therefore likely to require waste materials with a minimum solids content. A plant may elect to filter the waste materials on site during tank filling, pump-up to the kiln, or through the use of integral tank recycling/filtering systems.

Potential Waste Sources

Some 34 to 48 million metric tons of hazardous wastes were generated in the United States in 1980, according to EPA estimates. A significant portion of the industrial wastes generated in the U.S. may eventually be shown to be safe fuels for use in cement kilns. The greatest potential for using cement kilns appears to be in disposing of chlorinated wastes.

Approximately 650,000 metric tons of chlorinated hydrocarbon wastes were produced in the U.S. in 1977. Their types and distribution by states are shown in Table 14. Also shown is the amount of cement clinker produced by wet process cement plants in these states.

The largest potential sources of chlorinated waste fuels for cement plants are the production of vinyl chloride monomer, perchloroethylene, electronic components, and pharmaceuticals. Louisiana and Texas alone account for over 60 percent of the chlorinated waste generated in the United States. The greatest potential for applying cement kilns to the destruction of chlorinated wastes apparently lies in those two states.

The absence of wet kilns in certain states, such as Kentucky, New Jersey, and Illinois, does not preclude the use of chlorinated wastes from those states in cement kilns. Wastes from those states could be transported into neighboring states having wet process kilns although such an arrangement could entail diffculties in permitting or public acceptance.

LIABILITY AND INSURANCE

Section 5 concluded that the threat to health, environment and property of the cement plant and the surrounding area from burning industrial wastes is minimal given proper controls. To assess the economic impacts of these increased risks, this study also included a review of common industrial insurance practices to determine if any policy changes would be necessary for waste fuel use. Due to the unique nature of each company's policies, only general statements can be made about accepted practices. It seems likely that burning wastes in a kiln would not result in an absolute need for increased coverages except for the protection of the additional capital investment in the cement plant. Although the likelihood of actual population exposure is remote, public concern or future regulations may require a policy to cover "non-sudden" releases. The existence of such coverage may mitigate some of the community concerns, although the converse may also be true in some cases.

The hauler who would deliver the waste has special insurance needs, in some cases established by law or regulation. He is not included in this discussion.

TABLE 14. CHLORINATED WASTE GENERATION AND CEMENT PRODUCTION BY STATE (METRIC TONS/YR)

Source	State LA	TX	KY	CA	NY	PA	NJ	IL	TN	WV	Other Significant States	U.S. Totals
Vinyl Chloride Monomer Production	96,600	72,100	31,700	5,560	0	0	0	0	0	0	None	206,000
Perchloro-ethylene Production	84,400	61,900	9,850	2,820	0	0	0	0	0	0	KS-7,030	166,000
Electronic Components Manufacturing	*	446	*	2,330	3,080	1,190	772	913	*	*	MA-975 IM-524 FL-476 CT-318	13,900
Pharmaceutical Production	*	*	*	444	1,080	360	2,160	408	132	*	IM-444 CT&MI-264 ea. MO-144 MC-132	6,400
Carbon Tetrachloride Production	670	650	350	230	750	0	0	0	0	1,530	AL-1,000 KS-200	5,400
Methyl Chloride Production	1,430	0	140	0	530	0	0	0	0	410	MI-60	2,600
Chloroform Production	0	450	340	0	0	0	50	0	0	200	KS-140	1,200
Paints and Coatings Production	*	50	55	123	45	51	87	104	*	*	OH-78 MI-54 MO-40 GA-38	900
Other Sources	15,900	52,900	6,070	16,400	12,400	12,700	7,900	9,370	10,400	7,900	OH-8,480 MI-7,150 FL-6,620 MC-5,060	240,000
Totals	199,000	188,000	48,500	27,900	17,900	14,300	10,900	10,800	10,500	10,100	OH-9,300 KS-9,000 MI-7,400 FL-7,100	650,000
Wet Process Kiln Capacities (1000 MT/YR)	958	6,097	0	4,010	3,155	2,872	0	0	1,213	769	--	41,509

Sources: Schalit, L., et.al., "Incineration of Chlorinated Hydrocarbon Hazardous Wastes," ACUREX Corp., August, 1979.

Portland Cement Association, "U.S. Portland Cement Industry: Plant Information Summary," December, 1979.

Note: *Not shown but included in U.S. totals column figures.

Business Insurance Practice

The exact composition of a company's insurance is based upon many things. Among these are the seriousness of the possible event, its likelihood, legal requirements, the size of the firm and company policy.

Most business firms have comprehensive Commercial General Liability (CGL) insurance covering their operations. At a minimum, these cover third party liability for personal injury including death and property damages. Manufacturing firms frequently add to the general liability coverages an additional coverage for loss of profits during periods of business interruption caused by a named set of perils. This coverage may be in the form of an amendment to the general liability coverage and provides a pre-specified set of payments for business interruption.

While the above policies may be thought of as "standard", specific details may vary through the use of amendments which have the effect of tailoring the policies to the insured's requirements and the business practices of the insurance company. Business may supplement these coverages with additional coverages or policies, usually with other insurance companies such as:

- higher financial liability levels for catastrophic events or circumstances, a practice called "layering".
- specialized coverages to protect against risks of liability claims for which the firm may otherwise still be vulnerable.

An example of specialized coverage is environmental impairment liability. This coverage responds to claims against firms whose operations may cause or promote environmental pollution and consequent damage to persons, property and the environment in a local area.

Special Situations

The provisions within industrial insurance policies currently written which pertain to protection against claims arising out of the transportation, handling, storage, blending and burning of waste fuel mixtures are of particular interest.

The basic Comprehensive General Liability (CGL) policy will usually cover "sudden and accidental occurrences". Where the quality of the fuel mixture is closely controlled, such coverage is probably adequate. For example, in a form used by The Continental Insurance Companies, the coverage is provided by the language in the list of exclusions:

"This insurance does not apply:

...

(f) to bodily injury or property damage arising out of the discharge, dispersal, release or escape of smoke, vapors, soot, fumes, acids, alkalis, toxic chemicals, liquids or gases, waste materials or other irritants, contaminants or pollutants into or upon land, the atmosphere or any water course or body of water; but this exclusion does not apply if such discharge, dispersal, release or escape is sudden and accidental."

"Non-sudden and accidental" occurrences are not currently included in the "standard" comprehensive CGL policy. Research indicates that a policy which specifically covers damages to persons and property due to such releases to air, water or land is available only through a limited number of insurance firms (some of the larger industrial carriers are now becoming interested in providing this coverage). This coverage is of interest for firms engaged in handling and disposal of hazardous wastes because of financial requirements for hazardous waste management facility operators in the EPA Hazardous Waste Guidelines and Regulations (40 CFR Section 265).

In addition to insurance obtained from commercial firms, the possibility of government-backed insurance for hazardous waste disposal facilities has been studied. Some states, as well as the Federal government, are considering issuing environmental impairment liability insurance for hazardous waste treatment, storage and disposal facilities. Such insurance would be issued to assure the availability of adequate facilities and, presumably, only when the necessary coverage is not available from commercial insurance underwriters.

Where waste fuel mixtures are of such composition that long-term hazards are minimal, the need for coverage against non-sudden and accidental occurrences appears to be minimal. Risks involved would not exceed those to be expected in handling ordinary liquid fuels of comparable flammability characteristics.

If fuel mixtures could contain components with potentially hazardous effects over a period of time, the risk of damages through exposure of persons and property to these effects would require "non-sudden and accidental" coverage. Further, community concern may lead to providing such insurance policies to mollify public or regulatory sentiments for additional controls.

MODEL KILN CASE STUDY

Assumptions

An average-sized wet process plant has been hypothesized for a case study of the economics of burning industrial wastes. It is assumed that this plant has:

1. Two kilns with a capacity of 230,500 short tons/year/kiln.
2. Waste fuels delivered by truck.
3. Coal for heating kilns.
4. Air and water pollution control systems that meet Federal, State and Local requirements. Electrostatic precipitation for kiln/exhaust air has some over-capacity.
5. Sufficient dust disposal capacity located near the plant.
6. Adequate space for siting of any needed facilities.

The economic projections prepared in this case study should be considered to be rough estimates. The costs of installed equipment used in preparing these estimates may vary considerably depending on the specific needs of the plant.

Facility Requirements

Sections 4 and 5 discussed cement plants, their current status and health and safety aspects. Using those discussions as the foundation, this case study will build financial requirements for an industrial waste burning facility. The intent is to provide a safe, reliable system that will allow the kiln operator to benefit from the proposed burning while at the same time engendering community confidence.

Installed Equipment--

Included in this sub-section is the engineering, preparation and installation of those items which will become part of the plant-installed real property. This includes the clearing and preparation of an area for concrete slabs to support the waste

storage tank and the fuel oil tank. (The latter is intended for flushing lines between industrial waste runs.) The pumps, piping, instrumentation, metering, and electrical controls to transport and control the waste flow are also included.

Table 15 presents cost estimates of the installed equipment required to burn waste fuels. The total installed cost of required equipment is approximately $44,500. Safety and pollution control aspects are an important part of this package.

TABLE 15. ESTIMATED COST OF INSTALLED EQUIPMENT FOR MODEL CEMENT PLANT

Cost Element	Cost
Area preparation (cleaning, leveling, trenching, tamping)	$ 2,000
Concrete slabs (2)	3,200
Fuel tank	750
Steel industrial waste tank (25,000 gallons)	12,000
Tank diking	1,600
Truck unloading connections	500
Waste tank float level (with high and low alarm)	3,000
Piping and small fuel oil transfer pump	900
Piping and waste feed pump	3,000
Grounding	500
Flame arrestor	200
CO_2 fire protection system	2,200
Electrical equipment for	2,500
Normal fuel flow interruption	
Normal make-up air interruption sense	
Transducers	
Pump starter-shut off control	
Waste flow meter and instrumentation	1,200
Miscellaneous, hardware (NBFU coding, painting)	2,500
Nozzle assembly	450
Sub-total	36,500
Engineering and installation	8,000
Total Cost	$ 44,500

Source: Kearney estimates.

One cost element which potentially could be reduced is the carbon dioxide fire protection system. A less complicated water hose or sprinkler system could be substituted but would be less efficient against a fire associated with a spill. It is assumed that sufficient space is available so that fire walls

are not required around the storage tanks, although dikes to catch spills are included. Only one kiln is considered to be connected at a time to the industrial waste supply. Additional storage and transfer equipment and piping would be needed to serve both kilns simultaneously.

Portable and Miscellaneous Equipment--

Equipment is required for detection of leaks, problems, fire control and personnel protection. An austere project could reduce the cost estimates given in Table 16. However, it should be noted that this list could also be amplified if it was necessary to include pollutant barriers, material to absorb spills, etc.

TABLE 16. COST OF MISCELLANEOUS AND PORTABLE EQUIPMENT FOR A MODEL CEMENT PLANT

Cost Element	Cost
Portable fire extinguishers (large)	$1,200
Personnel protective equipment Self-contained breathing apparatus (2) Goggles Gloves Boots Organic respirators Dust respirators	2,100
Portable hydrocarbon detector/direct reading detector tubes	1,500
Total	$ 4,800

Source: Kearney estimates.

Recurring Costs

Labor, utility (electrical) and maintenance expenses will be experienced on a recurring basis. It is estimated that an average of two hours on the day shift and one hour on each of the other two shifts would be required for operating labor. A kiln utilization rate of 330 days per year is assumed. The bulk of the utility cost is electricity consumed by the waste fuel pump. Other electricity consumption includes the fuel pump and the operation of various controls. Maintenance on this installed equipment is estimated at about 5 percent of the investment cost (installed equipment). Recurring cost estimates, totaling approximately $15,800, are presented in Table 17.

TABLE 17. ANNUAL COSTS FOR A MODEL CEMENT PLANT

Cost Item	Cost
Labor: 330 days/yr. at 4 hrs/day at $8.00/hr.	$10,600
Utilities: Electricity	3,000
Maintenance Costs (5% of investment)	2,200
Total	$15,800

Source: Kearney estimates.

Insurance Costs

Insurance governing the "non-sudden and accidental" release of undesirable components is factored into this case study. Actual premiums will depend on many parameters that the insurance company uses. These include past experience with the company, management of the company, engineering controls, likelihood of an event occurring and deductible carried. The premium may vary considerably. For this case study, it is estimated at $15,000 per year.

Annualized Cost

The annualized cost is comprised of the fixed cost, including loan repayment over 5 years, interest, labor, utility, maintenance and insurance costs related to industrial waste burning. As shown in Table 18, annualized costs are estimated to be approximately $43,200 per year. On a production basis, this would be equivalent to a unit cost of 18.8 cents per ton of clinker (for the one 230,500-ton per year kiln utilized). Considering current cement costs, about $45 per ton, this is an insignificant outlay. Nevertheless, to compensate the cement manufacturer, he should be entitled to approximately a 15 percent return on his investment. This would require a total income from the operation of at least $49,700 a year.

Regulatory and Community Influences

The required standards established for compliance with various environmental laws are generally quantifiable but will vary between regions and states. Thorough prior consultation with regulators and the community is required before a decision is made to proceed with such an activity. There is no way to predict what demand may be made under such circumstances without a frank and complete exchange of views.

TABLE 18. ANNUALIZED COST FOR A MODEL CEMENT PLANT

Cost Item	Estimated Cost
Investment cost with 5 year payback	
($44,500 + $4,800) @ 13 percent for 5 years =	$12,400
Recurring costs	15,800
Insurance	15,000
Total	$43,200
Cost per ton of cement produced: $43,200/yr ÷ 230,500 tons/year = $0.188/ton	

Source: Kearney estimates.

Sampling and Analysis

As sampling and analysis requirements are still uncertain, their costs have not been included in this case study. It is assumed here that existing kiln monitoring systems are adequate.

Industrial Waste Pricing

The price of industrial waste or the fee charged for its disposal will vary with ease of disposal, heating value, chemical content, toxicity, reactivity, corrosivity, weight, viscosity, competition for the material, distance from generator or intermediary, and other related factors. The desirability of the waste and the price which can be paid will also vary with the price of alternative energy sources. The price used for the case studies is the price delivered to the kiln. It includes the original price for the waste (if any), transportation to the kiln and any intermediate costs such as blending. A possibility exists that kilns will be able to levy a disposal charge for accepting hard-to-dispose wastes. This has also been considered.

The two case studies given below show the effect of the price of the waste and the chlorine content of the waste. The price neglects the amount of neutralizing chemicals which might be saved. (This can vary significantly among plants.)

The following data is common to both case studies:

- Kiln Production
  240,000 tons/yr

- Fuel Cost (for conventional fuel)
  $2.46/million BTU

- Chlorine Limit
  0.6 % of kiln production or
  1,440 tons/yr

- Heat Value of Waste
  10,000 BTU/lb

- Investment + 15% return
  $50,000/yr

This data is used in calculating revenues resulting from two levels of waste fuel use and three levels of waste fuel costing.

Case 1

In the first case study it is assumed that a waste containing 20 percent by weight chlorine is available and that 80 percent of the waste's heating value can be recovered.

The maximum amount of waste that can be used, assuming a chlorine limit of 0.6 percent, is calculated to be the amount of chlorine that can be added, 1,440 tons/year, divided by the waste's chlorine content, 20 percent, or 7,200 tons of waste per year. The recovered heating value of the waste fuel used will total 1.15×10^{11} BTU. This is equivalent to a 7.9 percent fuel substitution.

If the waste is delivered at no cost to the cement plant, total savings will be $283,000 per year. Net savings, subtracting investment costs plus a 15 percent return on investment, would be $233,000 per year or 97 cents per ton of cement produced (for the one kiln utilized).

If the cement plant paid one dollar per million BTU of waste, net savings would be 49 cents per ton of cement produced.

If the cement plant charged a disposal fee equivalent to one dollar per million BTU of waste fuel heating value ($32 per ton of waste), net savings would be equivalent to $1.45 per ton of cement produced.

Figure 6 graphically illustrates the relationship between net savings and waste cost/disposal fee for a waste containing 20 percent chlorine. Curves are presented for both maximum fuel replacement, 7.9 percent of fuel needs, and for one-half the maximum fuel replacement or 3.95 percent of kiln fuel needs.

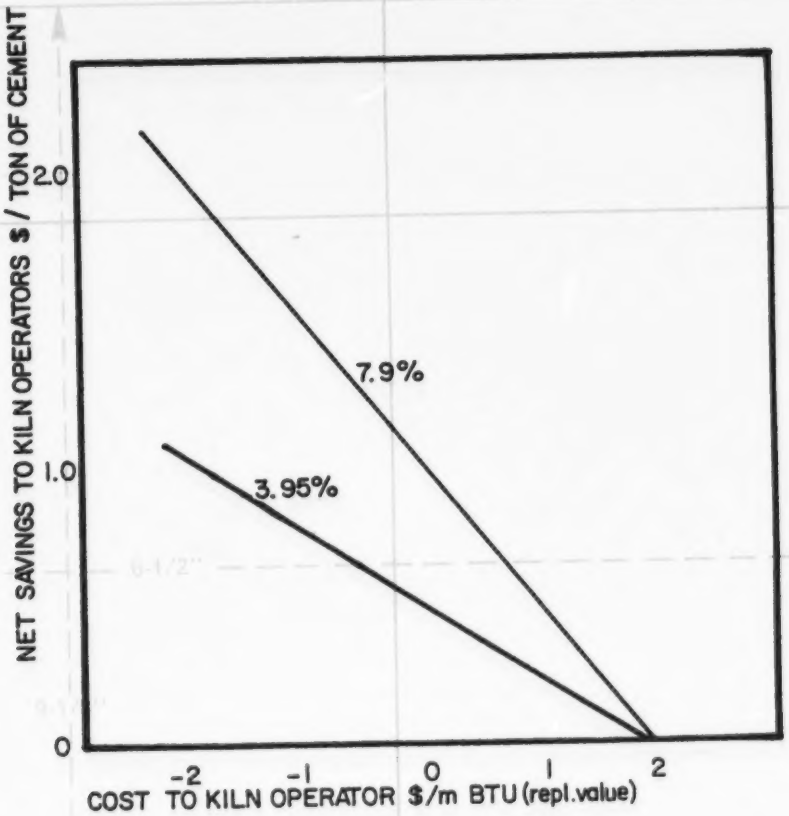

Figure 6. Net Savings Due to Substitution of Industrial Waste (20% Chlorine) for Fuel.

Note: 1. Fuel Cost is $2.46/million BTU
2. Heat Value of Waste in 10^4 BTU/lb
3. Total Chlorine Limit 0.6% of Cement Production
4. Capital Investment + 15% was Deducted to Give Net Savings

Case 2

In the second case study it is assumed that a waste containing 10 percent by weight chlorine is available and that 90 percent of the waste's heating value can be recovered.

The maximum amount of waste that can be used is calculated to be 14,400 tons per year. The recovered heating value of this quantity of waste is estimated to be 2.59×10^{11} BTU or 17.8 percent of the kiln's fuel requirements.

Net savings per ton of cement produced will be:

- $2.45 if the waste is delivered at no cost
- $1.37 if one dollar is paid per million BTU of waste fuel
- $3.53 if one dollar is charged per million BTU of waste fuel.

Figure 7 illustrates the relationship between net savings and waste costs/revenues for a waste containing 10 percent chlorine. Data are presented for both maximum fuel replacement, 17.8 percent of conventional fuel needs, and for one-half the maximum fuel replacement or 8.9 percent of kiln fuel needs.

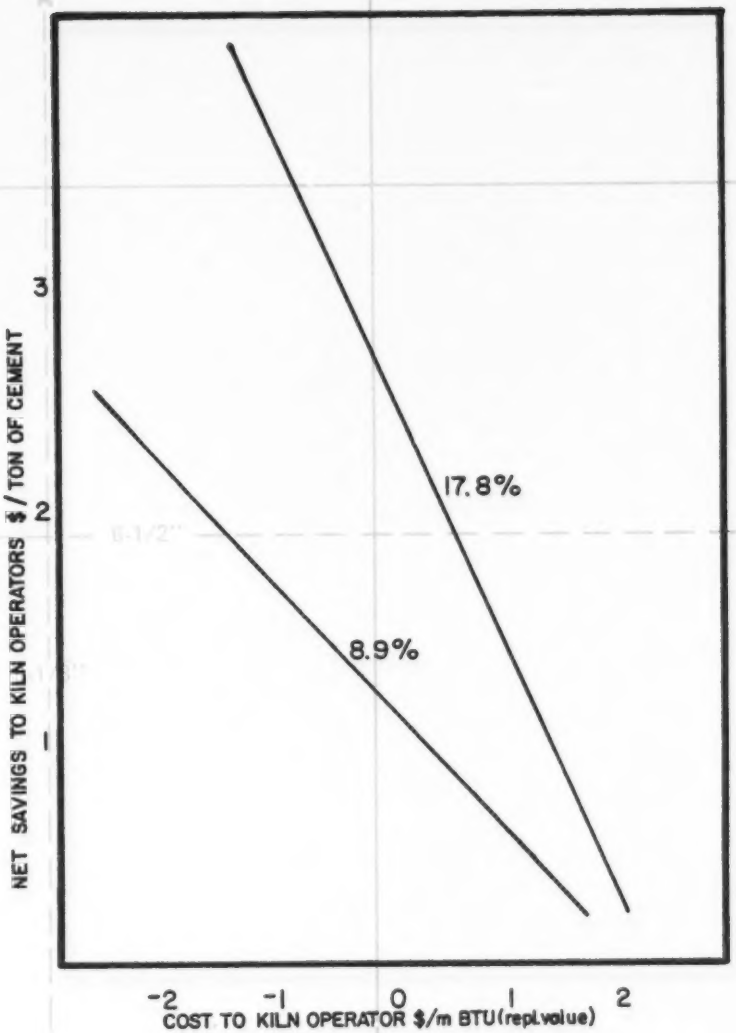

Figure 7. Net Savings due to Substitution of Industrial Waste (10% Chlorine) for Fuel.

Note: 1. Fuel Cost is $2.46/Million BTU.
2. Heat Value of Waste is 10^4 BTU/lb.
3. Total Chlorine Limit 0.6% of Cement Product
4. Capital Investment + 15% was deducted to Give Net Savings.

SECTION 7

RESEARCH NEEDS

The use of cement kilns for waste disposal is currently constrained by uncertainties on the part of regulatory authorities and cement plants concerning the safety and cost effectiveness of such practices. The research completed to date has successfully demonstrated that a strong potential exists for disposing of toxic wastes in cement kilns. However, this research has not completely resolved a number of issues which are critical to the implementation of this technique on a significant scale.

The research needed to foster the expanded use of waste fuels in the U.S. is identified in this section. It is recommended that further demonstration waste burns aimed at resolving existing uncertainties be conducted. The results of such a program should be incorporated into manuals for use by cement plants and regulatory authorities in evaluating proposed waste-fuel programs.

MONITORING REQUIREMENTS

Future research should attempt to identify the types of monitoring required at cement plants burning waste fuels. Emphasis should be placed on identifying the simplest monitoring requirements which are sufficient to assure the environmental adequacy of operations.

The identification of adequate monitoring systems entails a thorough understanding of the mechanism by which wastes are destroyed in cement kilns. Laboratory studies are likely to be very helpful in assessing the effects of time and temperature variations on waste decomposition kinetics. It is suggested that future studies in cement kilns be coordinated with laboratory research aimed at developing a mathematical model of waste destruction in cement kilns.

The University of Dayton Research Institute has developed a Thermal Decomposition Analytical System (TDAS) which may be useful in such work. In future research studies, wastes burned in cement kilns should be subjected to controlled thermal decomposition in a system similar to the University of Dayton's

TDAS. Not only would the use of such a system provide an understanding of time/temperature effects on decomposition, but it would also identify likely decomposition products which should be monitored in the cement kiln.

EMISSION CHARACTERIZATION

The emissions expected from the use of waste fuels should be further characterized and correlated with process variables. This work should focus on the generation of by-products during the combustion of chlorinated organic wastes.

The impacts of waste fuel use on sulfur dioxide (SO_2) and oxides of nitrogen (NO_x) emissions are unknown. Future studies should include work aimed at relating any SO_2 and NO_x emission rate changes to the quantities and characteristics of the waste fuels used.

Organic materials injected into kilns have consistently been destroyed to levels below analytical detection limits. However, trace levels (up to about 50 ppb) of lightweight organochloride compounds have been detected during the use of chlorinated waste fuels. Although such low emission levels do not appear to present significant environmental risks, the variables controlling their generation are not understood. Future research should attempt to define the paths by which these compounds enter the kiln exhaust. Because a plant feed water may be a source of these contaminants, future work should include coordinated monitoring of stack emissions and feed water constituents.

The characteristics and potential environmental impacts of cement kiln dust are not well understood. A significant characterization of kiln dust documenting variations between plants is needed but is probably beyond the scope of any waste-fuel study. Future studies with waste fuels should, however, attempt to identify the impacts of waste-fuel utilization on discarded dust. Particular emphasis should be placed on the change in leachate characteristics caused by the use of waste fuels. Leachate derived through EPA's extraction procedure tests of the dusts should be analyzed to determine the extent of any changes that could occur when burning waste fuels.

Ultimately, this work should be related to dust disposal practices. If potential exists for environmental damage as a result of leachate changes caused by waste fuel use, appropriate dust management practices should be identified. Where possible, future work with chlorinated wastes should attempt to identify potential uses for discarded kiln dust.

PARTICULATE CONTROL

The effect of halogenated wastes on kiln-dust generation rates is reasonably well understood. Lack of adequate particulate collection capacity may be a key factor restricting the use of chlorinated waste fuels. Research should be conducted to develop techniques for controlling emissions of the additional particulates generated when using halogenated waste fuels. This work should be oriented primarily towards plants employing precipitators, baghouses, and/or cyclones as these are the most commonly employed dust-control devices in the cement industry.

PLANT EQUIPMENT

The impacts of waste fuel use on plant equipment are not well understood. Although it appears that such impacts will be minimal, future studies should attempt to document the extent of excessive corrosion and wear attributable to burning waste fuels. Specifically, such studies should focus on corrosion of fan blades, refractory brick, baghouses, and precipitators resulting from acid fumes generated during the combustion of chlorinated wastes. Data confirming the lack of serious equipment damage would remove plant concerns which otherwise might impede the implementation of waste fuel programs.

ECONOMICS

The economic viability of using waste fuels will be a prime concern of cement plants. As the applicability of waste fuel use becomes clearer, data to support economic evaluations of long-term waste fuel use should be developed. Plants considering waste fuel use will almost certainly require firm cost/revenue estimates before seriously considering investing in such operations.

FURTHER DEMONSTRATIONS

The research needs identified in this section should be incorporated into additional demonstration projects. These demonstrations should be configured to confirm the results of prior studies and to resolve uncertainties which still exist. The broader data base created during additional demonstration projects would greatly enhance the transferability of results between plants.

The amount of work completed to-date limits the confidence with which projections can be made for plants considering the use of waste fuels. Detailed data from demonstrations conducted at a number of cement plants would obviously enhance the credibility of such projections.

Because of the excellent potential for using chlorinated waste fuels in wet process cement plants, future research should be directed in this area. It is also recommended that research with waste fuels be restricted to the use of materials other than highly stable or toxic wastes, such as PCB's, until sufficient work has been completed to provide an indepth understanding of the kinetics of thermal decomposition in cement kilns and the effects of process variables. Spent chlorinated solvents such as methylene chloride, perchloroethylene, or chlorotoluene are excellent materials for use in this work. The generation of a substantial data base with low-toxicity wastes would not only serve as a foundation for further work with more-toxic wastes but it would foster the use of those low-toxicity wastes in cement plants.

MANUALS OF PRACTICE

Future research is likely to confirm the excellent potential of cement kilns for safely disposing of industrial wastes. As the results of additional demonstration studies become available, it is recommended that manuals of practice be developed to foster the expanded use of waste fuels.

These manuals should be directed towards cement plant operators and regulatory authorities. They should contain descriptions of the types of wastes amenable to use as supplemental fuels, recommended operating procedures, equipment specifications, and descriptions of appropriate monitoring systems. In lieu of mandatory standards which may be imposed in the future, manuals of practice should provide criteria to determine the environmental impact and economic feasibility of proposed waste fuel operations.

CONCLUSION

It is the consensus of researchers that cement kiln disposal of organic industrial wastes will continue to demonstrate performance that is environmentally superior to other conventional disposal alternatives. The most significant impediment to the widespread implementation of this technology is likely to be public opposition from residents living in the vicinity of cement plants proposing to use waste fuels.

Additional research cannot totally eliminate such opposition nor can it sway a public that perceives a local cement plant as a "bad neighbor" because of past environmental abuses.

It can, however, provide cement plants having good community relations with the evidence necessary to defend the safety and legitimacy of proposed waste fuel operations. Future research is likely to be valuable in this respect by demonstrating not only the technical performance that can be expected, but by also demonstrating the successful involvement of local citizens in the planning and implementation of waste fuel programs.

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